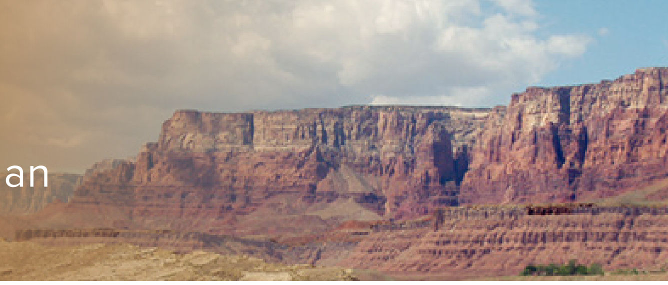
Glen Canyon Dam

Long-Term Experimental and Management Plan Environmental Impact Statement



FINAL

Volume 1—Chapters 1-8

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Bureau of Reclamation,
Upper Colorado Region
National Park Service,
Intermountain Region

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GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN FINAL ENVIRONMENTAL IMPACT STATEMENT

Joint-Lead Agencies
Bureau of Reclamation
National Park Service

Cooperating Agencies
Department of the Interior
  Bureau of Indian Affairs
  U.S. Fish and Wildlife Service
U.S. Department of Energy
  Western Area Power Administration
Arizona Game and Fish Department
Colorado River Board of California
Colorado River Commission of Nevada
Upper Colorado River Commission
Havasupai Tribe
Hopi Tribe
Hualapai Tribe
Kaibab Band of Paiute Indians
Navajo Nation
Pueblo of Zuni
Salt River Project
Utah Associated Municipal Power Systems

ABSTRACT

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation and National Park Service (NPS), proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam. The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years, consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, including those of importance to American Indian Tribes.

The Final Environmental Impact Statement (FEIS) was developed in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), and followed the implementing regulations developed by the President's Council on Environmental Quality in Title 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations implementing NEPA in 43 CFR Part 46. The FEIS analysis draws on the scientific information that has been collected under the Glen Canyon Dam Adaptive Management Program over the last 20 years to identify the potential environmental effects associated with taking no action, as well as a reasonable range of alternatives to no action for implementing the proposed federal action. Seven alternatives were considered and analyzed for the LTEMP EIS—a no action alternative (Alternative A), a hydropower-focused alternative (Alternative B), three condition-dependent alternatives (Alternatives C, D, and E), and two steady flow alternatives (Alternatives F and G). These alternatives incorporated a broad range of operations and experimental actions that together allowed for a full evaluation of possible impacts of the

proposed action. Based on the impact analyses conducted, DOI has chosen Alternative D as both the preferred and the environmentally preferred alternative. Alternative D is expected to result in an improvement in conditions for humpback chub, trout, and the aquatic food base; have the least impact on vegetation, wetlands, and terrestrial wildlife; improve sandbar building potential and conserve sediment; sustain or improve conditions for reservoir and river recreation; improve preservation of cultural resources; respect and enhance Tribal resources and values; and have limited impacts on hydropower resources.

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ACRONYMS AND ABBREVIATIONS

ac	acre(s)
ac-ft	acre-foot (feet)
ACHP	Advisory Council on Historic Preservation
AML	abandoned mine land
AMSL	above mean sea level
AMWG	Adaptive Management Work Group
AOP	Annual Operation Plan for Colorado River Reservoirs
APE	Area of Potential Effect
Argonne	Argonne National Laboratory
ASMR	Age-Structured Mark Recapture Model
AZGFD	Arizona Game and Fish Department
AZ-SGCN	Arizona Species of Greatest Conservation Need
BA	Balancing Authority (in Chapter 3 only) Biological Assessment (in all other sections)
BGEPA	Bald and Golden Eagle Protection Act of 1940
BIA	Bureau of Indian Affairs
BO	Biological Opinion
C	Celsius
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAEDYM	Computational Aquatic Ecosystem Dynamics Model
CCC	Civilian Conservation Corps
CEQ	Council on Environmental Quality
CFMP	*Comprehensive Fisheries Management Plan*
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPUE	catch per unit effort
CRBC	Colorado River Board of California
CRCN	Colorado River Commission of Nevada
CRD	Colorado River Discovery
CREDA	Colorado River Energy Distributors Association
CRMP	Colorado River Management Plan
CRSP	Colorado River Storage Project
CRSPA	Colorado River Storage Project Act of 1956
CRSS	Colorado River Simulation System
CSU	Colorado Springs Utilities

DEIS	Draft Environmental Impact Statement
Deseret	Deseret Generation and Transmission Cooperative
DFC	desired future condition
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DPS	Distinct Population Segment
EA	Environmental Assessment
eGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ELCOM	Estuary, Lake and Coastal Ocean Model
EMS	emergency medical services
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ESA	Endangered Species Act of 1973, as amended
F	Fahrenheit
FCPP	Four Corners Power Plant
FES	Firm Electric Service
FONSI	Finding of No Significant Impact
FR	*Federal Register*
ft	foot (feet)
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCM	general circulation model
GCMRC	Grand Canyon Monitoring and Research Center
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GCPA	Grand Canyon Protection Act of 1992
GHG	greenhouse gas
GMP	General Management Plan
GW	gigawatt(s)
GWh	gigawatt-hour(s)
GWP	global warming potential
H_2S	hydrogen sulfide
HBC	humpback chub
HFC	hydrofluorocarbon
HFE	high-flow experiment
hr	hour(s)

HRR	Hualapai River Runners
in.	inch(es)
IPM	Integrated Pest Management
IRP	integrated resource plan
ISM	Indexed Sequential Method
kaf	thousand acre-feet
kWh	kilowatt-hour(s)
lb	pound(s)
LCRMSCP	Lower Colorado River Multi-Species Conservation Program
LMM	Lake Mead Model
LMNRA	Lake Mead National Recreation Area
LROC	Long-Range Operating Criteria
LTEMP	Long-Term Experimental and Management Plan
LTEP	Long Term Experimental Plan
LTF	long-term firm
maf	million acre-feet
MAMB	miscellaneous algae, macrophytes, and bryophytes
MBTA	Migratory Bird Treaty Act
MCL	maximum contaminant level
mi	mile(s)
MLFF	Modified Low Fluctuating Flow
MMt	million metric tons
MOA	Memorandum of Agreement
MT	metric ton(s)
MW	megawatt(s)
MWh	megawatt-hour(s)
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NAU	Northern Arizona University
NC	no change
NEPA	National Environmental Policy Act of 1969, as amended
NERC	North American Electric Reliability Corporation
NEV	net economic use value
NGO	nongovernmental organization
NHPA	National Historic Preservation Act
NM	national monument
NO_2	nitrogen dioxide
NO_3	nitrate-nitrogen
NOI	Notice of Intent
NO_x	nitrogen oxides
NPS	National Park Service

NPV	net present value
NRHP	*National Register of Historic Places*
NTUA	Navajo Tribal Unit Authority

O&M	operation and maintenance
O_3	ozone
OPAC	Office of Planning and Compliance
OSMRE	Office of Surface Mining Reclamation and Enforcement

PA	Programmatic Agreement
Pb	lead
PEPC	Planning, Environment, and Public Comment
PFC	perfluorocarbon
P.L.	Public Law
PM	particulate matter
$PM_{2.5}$	particulate matter ≤2.5 μm in aerodynamic diameter
PM_{10}	particulate matter ≤10 μm in aerodynamic diameter
POM	particulate organic matter
PSAR	preventative search and rescue
PSD	Prevention of Significant Deterioration

RA	resource available
Reclamation	Bureau of Reclamation
RM	river mile
RMP	Resource Management Plan
ROD	Record of Decision
RSG	Reserve Sharing Group

SAAQS	State Ambient Air Quality Standards
SBM	Sand Budget Model
SCP	Salinity Control Project
SD	standard deviation
SDA	Structured Design Analysis
SE	standard error
Secretary, the	Secretary of the Interior
SF_6	sulfur hexaflouride
SHPO	State Historic Preservation Officer
SLCA/IP	Salt Lake City Area Integrated Projects
SO	Secretarial Order
SO_2	sulfur dioxide
SPC	Southern Paiute Consortium
SRP	Salt River Project
SRSG	Southwest Reserve Sharing Group

TCD	temperature control device
TCP	traditional cultural property

TDS	total dissolved solids
THPO	Tribal Historic Preservation Officer
TL	total length
TMF	trout management flow
Tri-State	Tri-State Generation and Transmission Association
TWG	Technical Working Group
UAMPS	Utah Associated Municipal Power Systems
UBWR	Utah Board of Water Resources
UCRC	Upper Colorado River Commission
UMPA	Utah Municipal Power Agency
USC	*United States Code*
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VOC	volatile organic compound
WACM	Western Area Colorado-Missouri Region
WALC	Western Area Lower Colorado Region
WAUW	Western Area Upper Great Plains West Region
WECC	Western Electricity Coordinating Council
Western	Western Area Power Administration
YOY	young-of-year
yr	year(s)
ZHHPO	Zuni Heritage and Historic Preservation Office

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1 INTRODUCTION

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation (Reclamation) and National Park Service (NPS) proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam, the largest unit of the Colorado River Storage Project (CRSP). The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, commonly referred to as the Colorado River Ecosystem,[1] including those of importance to American Indian Tribes.

This LTEMP Environmental Impact Statement (EIS) has been prepared to identify the potential environmental effects of implementing the proposed federal action. In addition, this EIS identifies and analyzes the environmental issues and consequences associated with taking no action, as well as a reasonable range of alternatives to no action for implementing the proposed federal action. The alternatives addressed in this EIS include a broad range of operations and experimental actions that together allow for a full evaluation of possible impacts of the proposed action. DOI, through Reclamation and NPS, has determined these alternatives represent a reasonable range of options that may meet the purpose, need, and objectives (as described below) of the proposed action. This EIS has been developed in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), following implementing regulations developed by the President's Council on Environmental Quality (CEQ) in Title 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations implementing NEPA in 43 CFR Part 46.

Reclamation and NPS are joint-lead agencies for the LTEMP EIS because of their roles in operating Glen Canyon Dam (Reclamation's role) and managing the resources of Glen Canyon National Recreation Area (GCNRA), Grand Canyon National Park (GCNP), and Lake Mead National Recreation Area (LMNRA) (NPS's role). As joint leads, both agencies have been equally involved in the development of all aspects of the LTEMP EIS. Major phases of LTEMP EIS development included (1) public and internal scoping, (2) identification of alternatives to be considered for evaluation and their characteristics, (3) identification of elements common to all alternatives, (4) analysis of the consequences of the alternatives, (5) government-to-government consultation with traditionally associated Tribes, (6) preparation and issuance of the Draft EIS (DEIS), (7) public review of the DEIS, and (8) issuance of this Final EIS.

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[1] The Colorado River Ecosystem is defined as the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources (see Appendix A).

The first EIS on the operation of Glen Canyon Dam was published in 1995 (Reclamation 1995). The 1996 Record of Decision (ROD) (Reclamation 1996) selected the Modified Low Fluctuating Flow Alternative as the preferred means of operating Glen Canyon Dam. The ROD incorporated the GCPA requirement that the Secretary of the Interior (hereafter referred to as the Secretary) undertake research and monitoring to determine if revised dam operations were achieving the resource protection objectives of the final EIS and the ROD. The ROD also led to the establishment of the Glen Canyon Dam Adaptive Management Program (GCDAMP), administered by Reclamation with technical expertise provided by the U.S. Geological Survey's (USGS's) Grand Canyon Monitoring and Research Center (GCMRC).

The following passages were included in the 1995 EIS for the purposes of providing background and context to the public. This section provides relevant content and context for this LTEMP EIS and is therefore reproduced here for public information:

> The underlying project purpose(s) is defined by section 1 of the Colorado River Storage Project Act of 1956 (43 United States Code (U.S.C.) 620), which authorized the Secretary to "construct, operate, and maintain" Glen Canyon Dam:
>
> "...for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the foregoing purposes..."
>
> In 1968, Congress enacted the Colorado River Basin Project Act (43 U.S.C. 1501 et seq.). This act provided for a program for further comprehensive development of Colorado River Basin water resources. Section 1501(a) states:
>
> "This program is declared to be for the purposes, among others, of regulating the flow of the Colorado River; controlling flood; improving navigation; providing for the storage and delivery of waters of the Colorado River for reclamation of lands, including supplemental water supplies, and for municipal, industrial, and other beneficial purposes; improving water quality; providing for basic public outdoor recreation facilities; improving conditions for fish and wildlife, and the generation and sale of electrical power as an incident of the foregoing purposes."
>
> In addition, the Criteria for Coordinated Long Range Operation of Colorado River Reservoirs (including Glen Canyon Dam) were mandated by section 1552 of the Colorado River Basin Project Act. Article 1.(2) of these criteria requires that the Annual Operating Plan for Colorado River reservoirs:
>
> "...shall reflect appropriate consideration of the uses of the reservoirs for all purposes, including flood control, river regulation, beneficial consumptive uses,

power production, water quality control, recreation, enhancement of fish and wildlife, and other environmental factors."

The Colorado River Compact (1922) and the Upper Colorado River Basin Compact (1948) do not affect obligations to Native American interests. Article VII and Article XIX, Part A, respectively, of the 1922 and 1948 compacts provide that:

"Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian Tribes."

The Colorado River Storage Project Act of 1956, the Colorado River Basin Project Act of 1968, and the associated Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (Long-Range Operating Criteria) did not alter these compact provisions.

In addition to the Secretary's decision calling for a reevaluation, Congress subsequently enacted the Grand Canyon Protection Act of 1992. Section 1802 (a) of the act requires the Secretary to operate Glen Canyon Dam:

"... in accordance with the additional criteria and operating plans specified in section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreational Area were established, including, but not limited to natural and cultural resources and visitor use."

Section 1802(b) of the act further requires that the above mandate be implemented in a manner fully consistent with existing law[2]. Section 1802(c) states that the purposes for which Grand Canyon National Park and Glen Canyon National Recreation Area were established are unchanged by the act. Section 1804 (a) of the act requires the Secretary to complete an EIS no later than October 30, 1994, following which, under section 1804 (c), the Secretary is to 'exercise other authorities under existing law, so as to ensure that Glen Canyon Dam is operated in a manner consistent with section 1802.' Section 1804 (c) also requires that the criteria and operating plans are to be 'separate from and in addition to those specified in section 602 (b) of the Colorado River Basin Project Act of 1968.'

Glen Canyon Dam was completed by the Bureau of Reclamation (Reclamation) in 1963, prior to enactment of the National Environmental Policy Act of 1969 (NEPA). Consequently, no EIS was filed regarding the construction or operation

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[2] The Secretary shall implement this section in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of the Colorado River Storage Project Act of 1956 (CRSPA) and the Colorado River Basin Project Act of 1968, that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin.

of Glen Canyon Dam. Since the dam has long been completed, alternatives to the dam itself have been excluded from the scope of the analysis.

The DOI has evaluated information developed through the GCDAMP to more fully inform decisions regarding operation of Glen Canyon Dam over the next 20 years and to inform other management and experimental actions within the LTEMP. Revised dam operations and other actions will be considered and analyzed under alternatives in this EIS.

The LTEMP will incorporate information gathered since the 1996 ROD, including status reports developed in coordination with the GCDAMP and Reclamation and NPS compliance documents supporting adaptive management efforts for the Glen Canyon Dam. These include, but are not limited to, the *Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam* (Reclamation 2011a), *Environmental Assessment for an Experimental Protocol for High-Flow Releases from Glen Canyon Dam* (Reclamation 2011b), Colorado River Management Plan (CRMP) (NPS 2006b), *EIS for 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (Reclamation 2007a), and the *Comprehensive Fisheries Management Plan* (CFMP) (NPS 2013e).

A previous planning process, called the Long Term Experimental Plan (LTEP) for the operation of Glen Canyon Dam, commenced in late 2006. In February 2008, the LTEP EIS was put on hold until the completion of environmental compliance on a 5-year plan of experimental flows (2008–2012), including a high-flow test completed in March 2008 and yearly fall steady flows conducted each year in September and October from 2008 to 2012. As stated in the Notice of Intent (NOI) in the *Federal Register* on July 6, 2011 (DOI 2011b), the LTEMP EIS supersedes the LTEP EIS. This LTEMP EIS draws on the environmental documentation and updated information developed for the LTEP EIS.

1.1 DESCRIPTION OF THE PROPOSED ACTION

The proposed federal action considered in this EIS, as described in the 2011 NOI and as further refined in this EIS, is the development and implementation of a structured, long-term experimental and management plan for operations of Glen Canyon Dam. The LTEMP and the Secretary's decision would provide a framework for adaptively managing Glen Canyon Dam operations and other management and experimental actions over the next 20 years consistent with the GCPA and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations (including hourly, daily, and monthly release patterns), non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements, maintain or improve hydropower production to the greatest extent practicable, consistent with improvement of downstream resources, including those of importance to American Indian Tribes. The locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and adjacent lands are shown in Figure 1-1. Glen Canyon Dam is shown in Figure 1-2.

This LTEMP EIS analyzes alternative-specific monthly, daily, and hourly releases from Glen Canyon Dam. Under the LTEMP, water will continue to be released in a manner that is

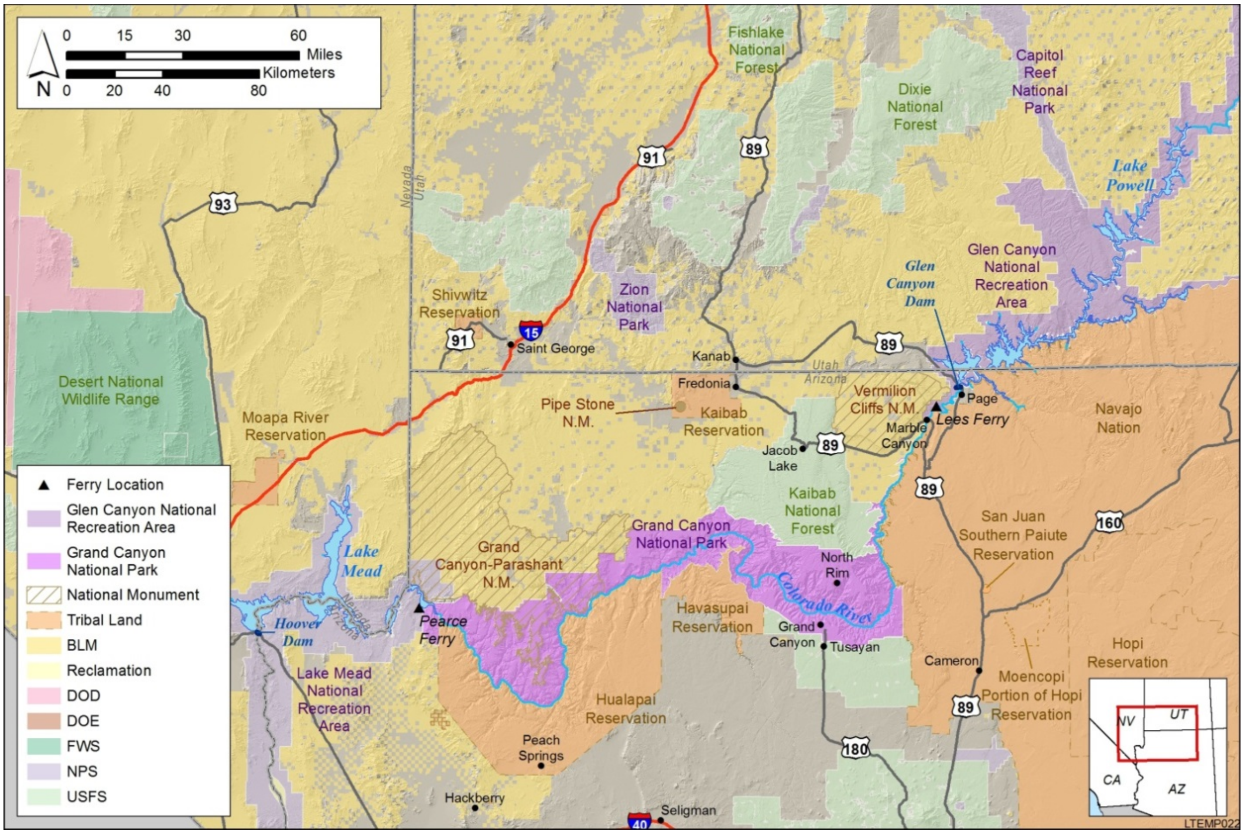

FIGURE 1-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands (This map is for illustrative purposes only, not for jurisdictional determinations; potential area of effects varies by resource and is addressed in Chapters 3 and 4.)

fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of the Colorado River Storage Project Act of 1956 (CRSPA) and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin, and consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria for (LROC) Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

1.2 PURPOSE OF AND NEED FOR ACTION

The purpose of the proposed action is to provide a comprehensive framework for adaptively managing Glen Canyon Dam over the next 20 years consistent with the GCPA and other provisions of applicable federal law.

FIGURE 1-2 Glen Canyon Dam

The proposed action will help determine specific dam operations and actions that could be implemented to improve conditions and continue to meet the GCPA's requirements and to minimize—consistent with law—adverse impacts on the downstream natural, recreational, and cultural resources in the two park units, including resources of importance to American Indian Tribes.

The need for the proposed action stems from the need to use scientific information developed since the 1996 ROD to better inform DOI decisions on dam operations and other management and experimental actions so that the Secretary may continue to meet statutory responsibilities for protecting downstream resources for future generations, conserving species listed under the Endangered Species Act (ESA), avoiding or mitigating impacts on *National Register of Historic Places* (NRHP)-eligible properties, and protecting the interests of American Indian Tribes, while meeting obligations for water delivery and the generation of hydroelectric power.

The purpose and need statement described above was modified from the July 6, 2011, *Federal Register* notice based on public and Cooperating Agency comments. The ESA Recovery Implementation Program was removed from the objectives in Section 1.4 and eliminated from further consideration for this EIS, as described in Section 2.2; other refinements to the purpose and need statement were not substantively different from those described in the original notice.

Several key issues related to resources downstream of Glen Canyon Dam, and new scientific information related to them, are summarized below:

- *Continued loss of sandbars*. The Colorado River downstream from Glen Canyon Dam is depleted of its natural sediment load due to the presence of the dam, and many types of ongoing dam releases further deplete sediment delivered to the main channel by causing erosion. However, high-flow releases, between approximately 30,000 and 45,000 cubic feet per second (cfs) that are triggered when there is sufficient sediment from the Paria River, mobilize sand stored in the river channel and redeposit it as sandbars and beaches and associated backwater and riparian habitats (Melis 2011). This LTEMP EIS uses current comprehensive scientific data and modeling to consider possible improvements related to the use of high-flow experiments (HFEs), as well as possible intervening flow operations that may help better achieve the goal of building and retaining sandbars.

- *Humpback chub.* Since the 1995 EIS, the status of the humpback chub (*Gila cypha*), listed as an endangered species, has continued to be an issue of concern since the population in Grand Canyon, the largest in existence, declined during the late 1990s, coincident with higher flow volumes, cooler water temperatures, and high nonnative trout abundance, but has since partially rebounded over the last decade when water temperatures were warmer and trout abundance lower (Yackulic et al. 2014; Yard et al. 2011). Uncertainty in future humpback chub population response to interactions among flows, nonnative trout, food base, and water temperatures remains. This EIS explicitly examines the scientific uncertainties related to the relationships among trout, temperature, and the humpback chub population and considers both flow (e.g., trout management flows) and non-flow options (e.g., mechanical removal) and adaptive and experimental actions to improve the status of humpback chub.

- *Rainbow trout fishery*. Rainbow trout (*Oncorhynchus mykiss*) are the basis of the recreational fishery at Lees Ferry. Since 1964, the tailwaters of Glen Canyon Dam have supported a recreational rainbow trout fishery that has grown in importance and reputation to anglers locally, nationally, and internationally. Anglers from around the world travel to Lees Ferry to fish for high-quality rainbow trout. This blue-ribbon recreational sport fishery has become a financial and economic mainstay for the community of Marble Canyon, the City of Page, and Coconino County, as well as contributing to the statewide economy. This EIS evaluates the effects of flow and non-flow actions of LTEMP alternatives and adapative and experimental actions on the Glen Canyon rainbow trout fishery.

- *Other native and nonnative fish*. In addition to humpback chub, the razorback sucker (*Xyrauchen texanus*), also listed as endangered, and three other native fish still occur in the Colorado River below Glen Canyon Dam. Razorback sucker were thought to be extirpated from the Grand Canyon but have recently been found in western Grand Canyon. Populations of bluehead and flannelmouth suckers have fluctuated since the 1995 EIS. Numerous nonnative fish species are also found in the Colorado River and tributaries, and are numerically dominated by rainbow trout above the Little Colorado River. Brown trout (*Salmo trutta*), channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*), and other species occur in many locations in lower numbers. There is concern that the nonnative fish compete with or prey upon the native or endangered fish to varying degrees. The effects of dam operations were examined in the 1995 EIS, and much additional information has been accumulated about the effects of dam operations on native and nonnative fish. This EIS applies the best available science and modeling methods to further consider the impacts of a variety of dam operations and non-flow actions on native and nonnative fish and guide future experimentation regarding these flow regimes to reduce the negative interactions of nonnative fish with native fish.

- *Cultural resources*. Cultural resources occur along the river corridor downstream from Glen Canyon Dam in Glen, Marble, and Grand Canyons. In this EIS, cultural and natural resources are treated separately; however, it is recognized that many Tribes view these resources as being interconnected and view the river system as an integral component of the cultural landscape. These resources are found both within the area directly affected by river flows as well as on elevated terraces that have not been inundated by flows since construction of the dam. Research conducted since the 1995 EIS on the relationship between sand deposits and wind processes continues to provide data that suggest that windblown sand changes the surface of some sites of archaeological and cultural concern where sand supply and wind are active agents (Draut and Rubin 2008; Draut 2012b; Sankey and Draut 2014). Additional research downstream from the dam is examining the relationship between dam operations and ongoing erosion in areas of limited sand supply (Collins et al. 2014). This LTEMP EIS reexamines these relationships in light of the most recent scientific studies.

- *Riparian vegetation*. Vegetation along the river corridor is affected by the magnitude and seasonal pattern of river flows. Vegetation studies conducted since 1995 indicate that riparian vegetation composition, structure, distribution, and function are closely tied to ongoing dam operations. This EIS considers approaches to protecting, mitigating adverse impacts on, and improving vegetation within the Colorado River Ecosystem.

- *Hydropower.* Power generated by Glen Canyon Dam serves 5.8 million retail customers in Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming. Since 1995, new modeling tools have been created to better analyze dam operations for hydropower and the impacts of altering operations on electrical generation and capacity. This LTEMP EIS applies peer-reviewed

> science and modeling methods to further consider the impacts of a variety of dam operations on power generation and capacity, and considers operations that can maintain or increase hydropower generation while protecting and improving downstream resources. The status of the Basin Fund would be considered prior to implementing experiments as explained in Section 2.2.4.3.

Additional concerns related to dam operations were raised by the public at scoping meetings and in comments submitted during the scoping of the EIS. Such concerns included restoration of the downstream Colorado River Ecosystem; reestablishment of ecosystem patterns and processes to their pre-dam range of natural variability; elimination or minimization of further beach erosion; facilitation of sediment redeposition; in situ maintenance and preservation of the integrity of cultural and archeological resources; elimination of adverse impacts and other direct, indirect, and cumulative impacts on native species and assistance in their recovery; nonnative fish management; assistance in repropagation of the native riparian plant communities; and improving the hydropower resource. Public scoping is discussed further in Section 1.5.

1.3 LEAD AND COOPERATING AGENCIES AND CONSULTING TRIBES

Federal agencies having management objectives include Reclamation, NPS, U.S. Fish and Wildlife Service (FWS), Bureau of Indian Affairs (BIA), and Western Area Power Administration (WAPA).

1.3.1 Lead Agencies

The DOI, through Reclamation and NPS, prepared this LTEMP EIS with assistance from Argonne National Laboratory (Argonne). Reclamation is primarily responsible for operating Glen Canyon Dam. NPS is primarily responsible for conservation of the natural and cultural resources and visitor experience in GCNP, GCNRA, and LMNRA. Reclamation and NPS are joint-lead agencies in this process and have cooperated on all aspects of the production of this LTEMP EIS, including the overall NEPA/EIS process, communication and consultation with Cooperating Agencies and other stakeholders, and project schedule.

1.3.2 Cooperating Agencies and Consulting Tribes

Reclamation and NPS initially invited 25 federal, Tribal, state, and local government agencies to participate as Cooperating Agencies. Regular meetings with Cooperating Agencies have been held during the LTEMP EIS development process.

In addition, 43 Tribes were formally invited to enter into government-to-government consultation. In accordance with the requirements identified in Executive Order (E.O.) 13175, “Consultation and Coordination with Indian Tribal Governments” (U.S. President 2000); the President’s memorandum of April 29, 1994, “Government-to-Government Relations with Native American Tribal Governments” (U.S. President 1994a); “Department of the Interior Policy on

Consultation with Indian Tribes;" the President's memorandum of November 5, 2009, "Tribal Consultation" (U.S. President 2009); agency-specific guidance on Tribal interactions; and applicable natural and cultural resource laws and regulations (e.g., NEPA, ESA, National Historic Preservation Act [NHPA], and Migratory Bird Treaty Act); Reclamation and NPS coordinate and consult with federally recognized Tribes whose interests might be affected by activities being considered in the LTEMP EIS. Regular meetings have been held with Tribes who indicated an interest in consultation in the LTEMP EIS development process.

The Cooperating Agencies include BIA, FWS, WAPA, Arizona Game and Fish Department (AZGFD), Colorado River Board of California, Colorado River Commission of Nevada, Upper Colorado River Commission, Salt River Project, Utah Associated Municipal Power Systems, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and the Pueblo of Zuni. Two additional Tribes—the Fort Mojave Indian Tribe and the Gila River Indian Community—accepted the invitation to participate as consulting parties. Nine others—the Pueblo of Santa Ana, the Fort Yuma Quechan, the Pueblo of Nambe, the Pueblo of Santa Clara, the Pueblo of Zia, the Southern Ute Indian Tribe, the Ute Mountain Ute Indian Tribe, the Paiute Indian Tribe of Utah, and Yavapai-Apache Nation—preferred to be on the mailing list and kept informed regarding the LTEMP EIS.

1.4 OBJECTIVES AND RESOURCE GOALS OF THE LTEMP

The DOI has identified several primary objectives of operating Glen Canyon Dam under the LTEMP, as well as more specific goals to improve resources within the Colorado River Ecosystem through experimental and management actions. These objectives and resource goals were considered in the formulation and development of alternatives in this EIS.

The following is a list of the objectives of the LTEMP:

- Develop an operating plan for Glen Canyon Dam in accordance with the GCPA to protect, mitigate adverse impacts to, and improve the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use, and to do so in such a manner as is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the U.S. Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River Basin Project Act of 1968 that govern the allocation, appropriation, development, and exportation of the waters of the Colorado River Basin (see Section 1.9.4) and in conformance with the Criteria for Coordinated Long-Range Operations of Colorado River Reservoirs which are currently implemented by the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Ensure the LTEMP does not affect water delivery to the communities and agriculture that depend on Colorado River water consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Consider potential future modifications to Glen Canyon Dam operations and other flow and non-flow actions to protect and improve downstream resources.

- Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

- Respect the interests and perspectives of American Indian Tribes.

- Make use of the latest relevant scientific studies, especially those conducted since 1996.

- Determine the appropriate experimental framework that allows for a range of programs and actions, including ongoing and necessary research, monitoring, studies, and management actions in keeping with the adaptive management process.

- Ensure Glen Canyon Dam operations and non-flow actions under the LTEMP are consistent with the GCPA, ESA, NHPA, CRSPA, and other applicable federal laws.

Reclamation and NPS developed resource goals considering public input and desired future conditions (DFCs) previously adopted by the Adaptive Management Work Group (AMWG). The following resource goals were identified:

1. *Archaeological and Cultural Resources*. Maintain the integrity of potentially affected NRHP-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

2. *Natural Processes*. Restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems.

3. *Humpback Chub*. Meet humpback chub recovery goals, including maintaining a self-sustaining population, spawning habitat, and aggregations in the Colorado River and its tributaries below the Glen Canyon Dam.

4. *Hydropower and Energy*. Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and

minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

5. *Other Native Fish*. Maintain self-sustaining native fish species populations and their habitats in their natural ranges on the Colorado River and its tributaries.

6. *Recreational Experience*. Maintain and improve the quality of recreational experiences for the users of the Colorado River Ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon.

7. *Sediment*. Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.

8. *Tribal Resources*. Maintain the diverse values and resources of traditionally associated Tribes along the Colorado River corridor through Glen, Marble, and Grand Canyons.

9. *Rainbow Trout Fishery*. Achieve a healthy high-quality recreational rainbow trout fishery in GCNRA and reduce or eliminate downstream trout migration consistent with NPS fish management and ESA compliance.

10. *Nonnative Invasive Species*. Minimize or reduce the presence and expansion of aquatic nonnative invasive species.

11. *Riparian Vegetation*. Maintain native vegetation and wildlife habitat, in various stages of maturity, such that they are diverse, healthy, productive, self-sustaining, and ecologically appropriate.

Overlying these goals is the understanding that operations under LTEMP will continue to deliver water in a manner that is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin, and consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. As such, water delivery is an overarching consideration for dam operations that will necessarily inform the actions that can be taken to achieve the resource goals set forth above.

1.5 SCOPE OF THE EIS

On December 10, 2009, then Secretary of the Interior Ken Salazar announced the need to develop the LTEMP for Glen Canyon Dam. The Secretary emphasized the inclusion of stakeholders, particularly those in the GCDAMP, in the development of the LTEMP. This decision triggered the NEPA process and the need to conduct public scoping in preparation of this LTEMP EIS.

The *Federal Register* NOI to prepare an EIS and hold public scoping meetings was published on July 6, 2011, which marked the beginning of the public comment period. The scoping comment period ended January 31, 2012. A total of six public meetings and one web-based meeting were held in Arizona, Colorado, Nevada, and Utah in November 2011. A total of 447 individuals, groups, or organizations submitted scoping comments. Results of the public scoping process are described in the Scoping Summary Report (Reclamation and NPS 2012). There have also been formal and informal consultations with Tribes, which are described in Chapter 5.

The affected geographic region and resources of interest and the primary issues of concern to the public identified in scoping are summarized in the following sections. These inputs were used by the lead agencies to formulate a suite of alternative actions that could meet the purpose and need of the proposed action and to guide the comparative analysis of impacts of the alternatives in this EIS. The alternatives are described in Chapter 2.

The annual amount of water released under the LTEMP will be determined by the LROC, which is currently implemented through the 2007 Interim Guidelines until 2026; the guidelines for determining annual releases after that date will be determined under a separate process pursuant to the terms of the 2007 Guidelines. The LTEMP EIS assumes the annual volumes would be determined in accordance with the LROC and evaluates the effects on resources from the management of monthly, hourly, and daily releases from Glen Canyon Dam under various alternatives.

1.5.1 Affected Region and Resources

In general, the region examined in this EIS includes the area potentially affected by implementation of the LTEMP (including normal management and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead. More specifically, the scope primarily encompasses the Colorado River Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. Portions of GCNRA, GCNP, and LMNRA outside the Colorado River Ecosystem were also included in the affected region for certain resources due to the potential effects of LTEMP operations. In addition, for resources such as socioeconomics, air quality, and hydropower, the affected region was larger and included areas potentially affected by indirect impacts of the LTEMP. The potentially affected regions for these resources are specifically identified in Chapters 3 and 4. Figure 1-1 portrays the project area in context with the geographic regions of northern Arizona, southwestern Utah, and southern Nevada.

1.5.2 Impact Topics Selected for Detailed Analysis

Topics for analysis in the EIS were selected on the basis of public scoping comments, joint-lead agency guidance, meetings with Tribes and stakeholders, and relevant laws and regulations. A complete list of issues raised and discussed during scoping is available in the Scoping Summary Report (Reclamation and NPS 2012). Direct, indirect, and cumulative impacts of the effects of the proposed action, in combination with the effects of past, present, and reasonably foreseeable future projects, were analyzed in the LTEMP EIS for the following impact topics:

- Water resources, including annual, monthly, and hourly patterns of releases, water temperature, and water quality;

- Sediment resources, including sand and sandbars within the active river channel, and sand that accumulates in the Colorado River delta of Lake Mead;

- Natural processes that support ecological systems within the Colorado River Ecosystem;

- Aquatic ecology, including aquatic food base for fishes, nonnative fishes (warmwater, coolwater, and trout), native fishes (including the endangered humpback chub and razorback sucker), and aquatic parasites;

- Vegetation, including Old High Water Zone vegetation, New High Water Zone vegetation, wetlands, and special status plant species;

- Wildlife, including terrestrial invertebrates, amphibians and reptiles, birds, mammals, and special status wildlife species;

- Cultural resources, including archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties, and ethnographic resources important to American Indian Tribes;

- Tribal resources, including vegetation, wildlife, fish, and wetlands, water rights, traditional cultural places, traditional knowledge, and continued access to important resources within Glen and Grand Canyons;

- Visual resources in GCNRA, GCNP, and LMNRA;

- Recreation, visitor use, and experience as related to fishing, boating, and camping activities in the Colorado River and on Lakes Powell and Mead;

- Wilderness and visitor wilderness experience;

- Hydropower, including the amount and value of hydropower generation at Glen Canyon Dam, marketable electrical capacity, capital and operating costs, and rate impacts;

- Socioeconomics, including recreational use values, nonuse economic value, employment and income, and environmental justice;

- Air quality effects related to changes in Glen Canyon Dam operations, including air emissions; and

- Climate change, including the effects of Glen Canyon operations on greenhouse gas emissions and the effects of climate change on future impacts of Glen Canyon Dam operations.

1.5.3 Impact Topics Dismissed from Detailed Analysis

The following topics suggested during scoping were dismissed from analysis in the LTEMP EIS for the reasons stated below:

- *Extirpated Species*. The reintroduction of extirpated species is beyond the scope of the LTEMP EIS, but was addressed for fish within the NPS Comprehensive Fisheries Management Plan (NPS 2013e).

- *Prime and Unique Agricultural Lands*. The Farmland Protection Act of 1981, as amended, requires federal agencies to consider adverse effects on prime and unique farmlands resulting in conversion of these lands to nonagricultural uses. There are no agricultural lands in GCNP or GCNRA, and proposed alternatives would not have direct or indirect effects on downstream agricultural lands. Therefore, this topic is dismissed from further analysis.

- *Land Use in GCNP and GCNRA*. Land use and development of visitor and park facilities in GCNP and GCNRA are managed under the NPS Organic Act, NPS 2006 Management Policies (NPS 2006a) and associated Directors' Orders, GCNP and GCNRA enabling legislation, the Wilderness Act, and other such policies and regulations. None of the proposed alternatives would fundamentally affect land use in the project area. Therefore, this topic is dismissed from further consideration.

- *Soundscapes.* For the LTEMP EIS, soundscapes are not addressed as an individual resource; however, effects of man-made noise are discussed under the following impact topics: Wildlife (Section 4.7); Recreation, Visitor Use, and Experience (Section 4.11); and Wilderness (Section 4.12). Impacts on soundscape are expected to be negligible on the small number of days when noise-producing fish management and vegetation restoration activities take place.

1.6 ROLE OF ADAPTIVE MANAGEMENT

Since the 1996 ROD was signed by the Secretary, adaptive management has played a significant role in the operations of the Glen Canyon Dam and management of the resources downstream. The DOI is committed to continuing the Adaptive Management Program and Adaptive Management Work Group. The DOI promotes the use of adaptive management as a tool for resource management (DOI 2008) and has adopted the following definition put forth by the National Research Council's Panel on Adaptive Management for Resource Stewardship (NRC 2004):

> Adaptive Management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals; increases scientific knowledge; and reduces tensions among stakeholders.

In addition, the DOI (Williams et al. 2009) published a technical guide describing how and in what situations one can implement adaptive management.

1.6.1 History of the Existing Adaptive Management Program

The 1996 ROD specified several environmental commitments, the first of which was adaptive management. The GCDAMP was established to comply with the monitoring and consultation requirements of the GCPA. The components of the GCDAMP were first proposed in the 1995 Glen Canyon Dam EIS, and it was established in 1997 under the direction of the Secretary of the Interior.

The GCDAMP creates a process for monitoring and assessing the effects of current operations of Glen Canyon Dam on downstream resources and using the results to develop recommendations for modifying operating criteria and other resource management actions. The GCDAMP includes the AMWG, a federal advisory committee that is appointed by the Secretary. The AMWG consists of stakeholders, including federal and state resource management agencies; representatives of the seven basin states; American Indian Tribes; contractors for the purchase of federal hydroelectric power; environmental and conservation organizations; recreational; and other interest groups. The AMWG recommends suitable monitoring and research programs and may make other recommendations to the Secretary as well. The Technical Working Group (TWG) was also proposed in the 1995 EIS and was established to serve as a technical subcommittee to the AMWG. The GCMRC serves as the research branch of the GCDAMP, under the authority of the USGS. Monitoring and research conducted by GCMRC and others since 1996 have improved the understanding of riverine geomorphology and how dam operations can assist in the conservation of natural and cultural resources below the dam. The GCDAMP also includes an external and independent scientific review panel, the science advisors, who serve to peer review research and monitoring programs of the GCDAMP.

1.6.2 Relationship of Adaptive Management to NEPA and Changes to Operations

The 1995 EIS (Reclamation 1995) described adaptive management as the process "whereby the effects of dam operations on downstream resources would be assessed and the results of those resource assessments would form the basis for future modifications of dam operations." In describing the commitment to adaptive management in the 1996 ROD (Reclamation 1996), the Secretary specified that "any operational changes will be carried out in compliance with NEPA." In the 2011 NOI (DOI 2011b) that announced the LTEMP process, the DOI specified that a NEPA process would be used to document and evaluate impacts of the alternatives. By articulating and planning for critical uncertainties (Sections 1.7 and 2.1, and Appendix C) upfront, the LTEMP EIS puts forth an adaptive management plan for the next 20 years that is flexible and allows the experimental, operational, and management changes specified and analyzed in the LTEMP to proceed without additional NEPA analysis.

The LTEMP uses an adaptive management and experimental framework to refine existing information regarding the effects of dam operations and management actions on affected resources. Information gathered through the adaptive management and experimental process may be used to adjust operations within the range of the actions analyzed for impacts in this EIS.

1.7 ROLE OF DECISION ANALYSIS IN THE EIS PROCESS

The joint lead agencies used a structured decision analysis process to support the evaluation of alternatives in response to requests from some of the Glen Canyon Dam AMWG stakeholders to have additional substantive input into the EIS. The joint leads view structured decision analysis as a structured, scientific method to help evaluate complex alternatives; integrate information and critical uncertainties regarding the effects of independent environmental processes and resource response on outcomes; and bring additional transparency to the EIS process.

While structured decision analysis informed the analysis of the joint leads, it was not the only method by which a preferred alternative was identified. The identification of a preferred alternative was based on the full EIS analysis and considerations relating to qualitative and quantitative evaluations of impacts. Public comment, socioeconomic considerations, AMWG stakeholder input, and other factors were also considered in this identification.

The joint-lead agencies partnered with the USGS Patuxent Wildlife Research Center to incorporate formal decision-analysis tools in the LTEMP EIS. Decision-analysis tools are used to help formally parse out complex problems into manageable pieces, while keeping track of multiple objectives (Gregory and Keeney 2002). Appendix C further describes the decision-analysis tools and methodology as related to the LTEMP EIS.

The joint-lead agencies, other DOI agencies, including the BIA, FWS, and USGS, and Argonne technical staff developed performance metrics to evaluate achievement of the resource goals, identified critical uncertainties, and evaluated a preliminary and final set of alternatives in a process that incorporated decision-analysis tools. Performance metrics provide a quantitative, transparent, and objective method to assess the performance of the alternatives against each of the resource goals. Input from some Cooperating Agencies, Tribes, and other stakeholders was used to prepare a final set of performance metrics used in the LTEMP EIS analysis. Six of the seven Basin States and some of the Tribes and other stakeholders elected not to participate in this process for various reasons. The resulting performance metrics are presented in Appendix B.

Participating stakeholders ranked and weighted the importance of each performance metric according to their preferences for the value of the metric to swing from its lowest to its highest value, representing the range of effects on resources measured by the metric. This process is referred to as "swing-weighting." The results of swing weighting under structured decision analysis are included in the analysis of alternatives in Chapter 4 and are discussed in further detail in Appendix C.

While the decision analysis process helped inform the analysis of the joint-lead agencies, it was not used as the method by which a preferred alternative was identified or the only method by which the environmental impacts were fully analyzed. The determination of the preferred alternative was based on the analyses presented in this EIS. Furthermore, public comment, socioeconomic considerations, AMWG stakeholder input, and other factors were considered in the preparation of this EIS.

1.8 HISTORY, LOCATION, AND SETTING

1.8.1 History and Purpose of Glen Canyon Dam

Glen Canyon Dam, pictured in Figure 1-2, was authorized by CRSPA and completed by Reclamation in 1963 (DOI 2011b). Glen Canyon Dam is the second highest concrete-arch dam in the United States (exceeded only by the Hoover Dam) and rises 710 ft above bedrock within the steep sandstone walls of Glen Canyon. It was constructed to harness the potential of the Colorado River to provide for the water and power needs of millions of people (Reclamation 2008a).

The CRSPA was enacted for "the comprehensive development of the water resources of the Upper Colorado River Basin, for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the foregoing purposes." The Glen Canyon Dam is specifically managed to regulate the release of water in a way that allows the Upper Colorado River Basin states of Utah, Colorado, Wyoming, and New Mexico to use their share of the Colorado River water. It also helps provide water to the Lower Colorado River Basin states of California, Nevada, and Arizona, consistent with the Colorado River Compact of 1922 and subsequent water delivery commitments (DOI 2011b). There is more than 26 million acre-feet (maf) of water storage capacity in Lake Powell, created by Glen Canyon Dam. This stored water has made it possible to successfully sustain the needs of cities, industries, and agriculture throughout the West during extended dry periods (Reclamation 2008a).

As identified under the CRSPA, another authorized purpose of Glen Canyon Dam is to generate hydroelectric power, which is a clean, renewable, and reliable energy source (DOI 2011b). The hydroelectric power is marketed and delivered by WAPA to municipalities, rural electric cooperatives, American Indian Tribes, and governmental agencies in Wyoming, Utah, Colorado, New Mexico, Arizona, and Nevada. The dam's hydroelectric generators, which have a total capacity of 1,320 megawatts (MW), produce about 5 billion kilowatt-hours (kWh) of hydroelectric power annually to help meet the electrical needs of about 5.8 million customers (Reclamation 2008a). In addition, Glen Canyon Dam serves as a backup facility for power and transmission outages across the Southwest. Revenues from production of hydropower fund the Basin Fund, including the operations and maintenance of CRSP facilities, repay costs for participating projects, and help fund the Salinity Control Forum and many important environmental programs associated with Glen and Grand Canyons (Reclamation 2008a).

1.8.2 Location of Glen Canyon Dam and LTEMP Affected Area

The location of Glen Canyon Dam is shown in the upper right-hand corner of Figure 1-3, which shows the LTEMP affected area from Glen Canyon Dam to Lake Mead. Below Glen Canyon Dam, the Colorado River flows for 15 mi through the GCNRA, which is managed by NPS and encompasses more than 1.2 million acres of land in northern Arizona and southern Utah (DOI 2011b; NPS 2013c).

At about 15 mi downstream from the dam, Lee Ferry, Arizona, marks the end of Glen Canyon and the official division between the upper and lower Colorado River (Reclamation 2008b, 2011b). The confluence of the Paria River represents the beginning of Marble Canyon and the northern boundary of GCNP. For the next 277 mi, the Colorado River flows through the GCNP to Pearce Ferry, which marks the upper reaches of Lake Mead. Lake Mead extends from Pearce Ferry to Hoover Dam.

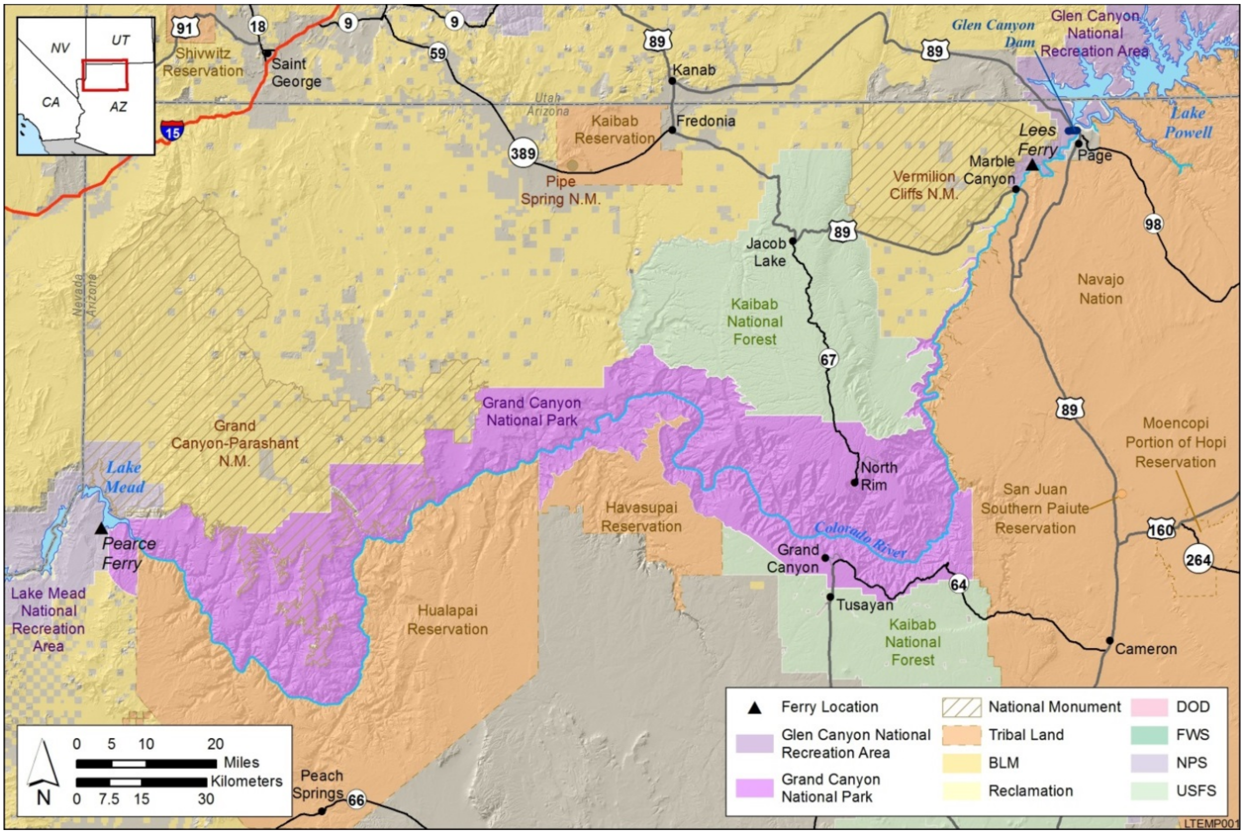

FIGURE 1-3 Map of the Colorado River between Lake Powell and Lake Mead (This map is for illustrative purposes only, not for jurisdictional determinations; potential area of effects varies by resource and is addressed in Chapters 3 and 4.)

The western boundary of the Navajo Indian Reservation lies near the Colorado River from Lake Powell through Glen and Marble Canyons. However, various orders and statutes reserved and withdrew land within one-quarter mile of the Colorado River to the United States for power purposes. The Kaibab Paiute Indian Reservation is on the plateau north of GCNP. The Havasupai Indian Reservation surrounds upper Havasu Creek, immediately south of GCNP. The Hualapai Indian Reservation comprises the southern portion of western Grand Canyon, adjacent to GCNP.

1.8.3 Operation of the Glen Canyon Dam

Glen Canyon Dam currently operates under the Modified Low Fluctuating Flow (MLFF) regime in conjunction with an adaptive management program outlined in the 1996 ROD for the 1995 EIS (Reclamation 1996). Dam releases are made according to the MLFF constraints and are presented in Table 1-1.

TABLE 1-1 Glen Canyon Dam Release Constraints under Modified Low Fluctuating Flows (after Reclamation 1995)

Parameter	Value	Conditions
Flow		
Maximum[a]	25,000 cfs	
Minimum	5,000 cfs	7:00 p.m. to 7:00 a.m.
	8,000 cfs	7:00 a.m. to 7:00 p.m.
Ramp Rates		
Ascending	4,000 cfs/hour	
Descending	1,500 cfs/hour	
Daily Flow Range[b]	5,000 to 8,000 cfs	

[a] May be exceeded for emergencies and during extreme hydrological conditions.

[b] Daily flow range limit is 5,000 cfs for months with release volumes less than 0.6 maf; 6,000 cfs for monthly release volumes of 0.6 maf to 0.8 maf; and 8,000 cfs for monthly volumes over 0.8 maf.

The 1995 EIS analyzed an array of reasonable alternatives “to allow the Secretary to balance competing interests and to meet statutory responsibilities for protecting downstream resources and producing hydropower, and to protect affected Native American interests.” The goal of selecting a preferred alternative in the 1996 ROD was “not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability.” MLFF was selected as the preferred alternative in that ROD (Reclamation 1996). The 1996 ROD reduced daily flow fluctuations below those of historic release patterns and provided occasional high steady releases of short duration (referred to as Habitat Maintenance Flows or Beach Habitat Building Flows) to protect or enhance downstream resources while allowing limited flexibility for power operations.

Dam operations are affected by a number of physical factors, such as reservoir elevation, annual runoff, and discharge capacity. Operations are also constrained by legal and institutional factors specified in federal laws, interstate compacts, international treaties, and Supreme Court decisions. Criteria and guidelines for annual operations are contained in the LROC and 2007 Interim Guidelines as determined by the Secretary, with participation by the Basin States.

Water can be released from Glen Canyon Dam in three ways—via powerplant, river outlet works, and spillway releases. Powerplant releases are the largest and preferred means of release, as they result in the generation of hydroelectric power. The powerplant houses eight electric generator turbines, which have the capacity to produce a maximum of 1,320 MW of electric power.

The powerplant can release a maximum of about 33,200 cfs of water. Maximum discharges are less when the reservoir is less than full, while MLFF limits maximum flows to 25,000 cfs under normal circumstances.

River outlet works bypass the powerplant, with releases of up to 15,000 cfs, and are almost always combined with powerplant releases, with a maximum operational release capacity of about 48,200 cfs.

Spillway releases are only used to avoid overtopping of the dam or to lower the level of Lake Powell based on emergency and safety constraints. Such releases bypass both the powerplant and the river outlet works. The reservoir elevation at which the spillways could be accessed is 3,700 ft. The combined capacity of the right and left spillways is 208,000 cfs. Spillway releases are avoided whenever possible; the combined release capacity of all three means of release is about 256,000 cfs.

1.8.4 History, Purpose, and Significance of the National Park System Units

The overarching purpose of the National Park System, as set forth in the NPS's Organic Act, "is to conserve the scenery, natural and historic objects, and wild life in the System units and to provide for the enjoyment of the scenery, natural and historic objects, and wild life in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (54 USC § 100101(a)). Each unit of the National Park System is authorized or established by an act of Congress or Presidential proclamation (or sometimes both) to conserve the unit's unique and significant resources. A park's purposes, as described in its enabling legislation or proclamation, are the foundation on which later management decisions are based to conserve resources while providing for the enjoyment of future generations. This mission is further discussed and clarified in *Management Policies 2006* (NPS 2006d). Described below are the park system units relevant to this project: GCNP, GCNRA, and LMNRA.

1.8.4.1 Grand Canyon National Park

GCNP was established as a National Monument in 1908, given National Park status in 1919, and recognized as a World Heritage Site in 1979 (NPS 1995). The park attracts nearly 5 million visitors annually from the United States and around the world. The purpose of the park "is to be managed to preserve and protect its natural and cultural resources and ecological processes, as well as its scenic, aesthetic and scientific values; and provide opportunities for visitors to experience and understand the environmental interrelationships, resources, and values of the Grand Canyon without impairing the resources" (NPS 1995). Specifically, "the purpose of Grand Canyon National Park is to preserve and protect Grand Canyon's unique geologic, paleontologic, and other natural and cultural features for the benefit and enjoyment of the visiting public; provide the public opportunity to experience Grand Canyon's outstanding natural and cultural features, including natural quiet and exceptional scenic vistas; and protect and interpret Grand Canyon's extraordinary scientific and natural values" (NPS 2010a).

The significance of GCNP can be found in the richness of its resources (NPS 2010a):

> Grand Canyon is one of the planet's most iconic geologic landscapes. During the last 6 million yr, the Colorado River carved Grand Canyon; these same erosional and tectonic processes continually shape the canyon today. Grand Canyon's exposed layers span more than one-third of Earth's history, and record tectonic and depositional environments ranging from mountain building to quiet seas. Taken as a whole, Grand Canyon, with its immense size, dramatic and colorful geologic record exposures, and complex geologic history, is one of our most scenic and scientifically valued landscapes.
>
> The force and flow of the Colorado River along with its numerous and remarkably unaltered tributaries, springs, and seeps provide plants and animals an opportunity to flourish in this otherwise arid environment. These vital resources represent transmission of local aquatic recharge from high-elevation rims to the arid inner canyon. There are hundreds of known seeps and springs throughout the park, and probably more to be discovered.
>
> Wilderness landscapes are an important current resource. Park boundaries extend beyond canyon walls to include 1,904 sq. miles (1,218,376 acres) of which 94 percent is managed as wilderness. When combined with additional contiguous public and Tribal lands, this area comprises one of the largest U.S. undeveloped areas. Grand Canyon offers outstanding opportunities for visitor experiences including extended solitude, natural quiet, clean air, dark skies, and a sense of freedom from the mechanized world's rigors.

GCNP is considered one of the finest examples in the world of arid-land erosion (NPS 1995). The park contains several major ecosystems, from the mixed Mohave Desert scrub of the lower canyon to the coniferous forests of the North Rim, and serves as an ecological refuge for relatively undisturbed remnants of dwindling ecosystems (such as boreal forest and desert riparian communities) and numerous rare, endemic, or specially protected (threatened/endangered) plant and animal species, including the California condor (NPS 1995, 2013c). The Grand Canyon protects an important cultural history. More than 12,000 years of human occupation have resulted in an extensive archeological record. The park preserves thousands of archeological sites, many of which remain unknown.

Eleven American Indian Tribes have known ties to the Grand Canyon, and some consider the canyon their original homeland and place of origin. The 11 federally recognized associated Tribes are Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Las Vegas Band of Paiute Indians, Moapa Band of Paiute Indians, Navajo Nation, Paiute Indian Tribe of Utah, San Juan Southern Paiute Tribe, Yavapai-Apache Nation, and Zuni Tribe.

The scenic vistas, qualities, and values of GCNP are internationally recognized and include a variety of landscapes and water features. The Grand Canyon is also known for its natural quiet and opportunities for solitude. The natural, cultural, and scenic qualities of the

Grand Canyon give rise to inspirational and spiritual values and a sense of timelessness (NPS 1995).

1.8.4.2 Glen Canyon National Recreation Area

The GCNRA was established by Congress in 1972 and occupies approximately 1,255,000 ac of northern Arizona and southeastern Utah adjacent to Lake Powell (NPS 1979). Congress directed NPS to manage the GCNRA so as to provide for public outdoor recreation use and enjoyment of Lake Powell and lands adjacent thereto in the States of Arizona and Utah and to preserve scenic, scientific, and historic features contributing to public enjoyment of the area (Public Law [P.L.] 92-593). In 2012, GCNRA attracted approximately 2 million visitors (NPS 2014f), of which approximately 10,000 utilized the Lees Ferry trout fishery.

The GCNRA ecosystem typifies the Colorado Plateau, supporting habitat for a diverse range of plants and animals. The region is arid to semi-arid, and the ecosystem is complex and often fragile (NPS 1979). Several rare and federally listed plant and animal species within the Colorado River Ecosystem are found in the GCNRA (NPS 2013b) and are addressed in Sections 3.6.3 and 3.7.5.

Glen Canyon has been occupied periodically by humans from about 11,500 years ago through the present (NPS 1979, 2013a). Several different prehistoric cultures and current Native American groups are represented in the cultural history of Glen Canyon, and the recreation area occupies a cultural interface zone, where different groups historically came into contact with one another (NPS 2013a). In the late 1800s, the crossing at Lees Ferry and the Hole-in-the-Rock trail became important points on the migration route of Mormon settlers moving westward (NPS 1979).

1.8.4.3 Lake Mead National Recreation Area

The LMNRA was established on October 8, 1964. Its purpose is to provide diverse public recreation, benefit, and use on Lakes Mead and Mohave and surrounding lands in a manner that preserves the ecological, geological, cultural, historical, scenic, scientific, and wilderness resources of the park. LMNRA includes two reservoirs, Lakes Mead and Mohave, along 140 mi of the former Colorado River from the southern tip of Nevada to the northwest corner of Arizona. It occupies approximately 1,495,800 ac in southeastern Nevada and northwestern Arizona, and is the fourth largest unit of the national park system outside the state of Alaska. Approximately 60% of the park is located in Arizona and 40% is located in Nevada (NPS 2002c).

LMNRA offers dramatic scenery and a diverse array of land- and water-based recreational opportunities in close proximity to several large urban centers of the southwestern United States. With more than 6 million visitors each year, the park supports some of the nation’s highest levels of water-based recreational and backcountry use and is an integral component of the region’s economy (NPS 2002c).

Situated in the northeastern Mojave Desert near the interface with the Great Basin Desert to the north and the Sonoran Desert to the south, LMNRA preserves a great diversity of biological resources, intact habitat, and ecological connectivity in the region, including many threatened and endangered species and rare natural communities. It showcases a remarkable collection of geological and paleontological features spanning more than 1.7 billion years of earth history (USGS 2014a). The diversity of cultural resources found at LMNRA—both on land and submerged—remains as evidence of a 10,000-year continuum of human history in the region (NPS 2013f). LMNRA also includes vast backcountry and wilderness lands, including nine separate designated wilderness areas that serve to preserve ecological resources and processes and provide exemplary opportunities for primitive recreation and desert solitude (NPS 2002c).

1.8.5 Tribal Lands

Numerous laws and treaties have established Indian reservations within or adjacent to the project area (see Figure 1-4). Traditional territory and traditional use lands extend well beyond

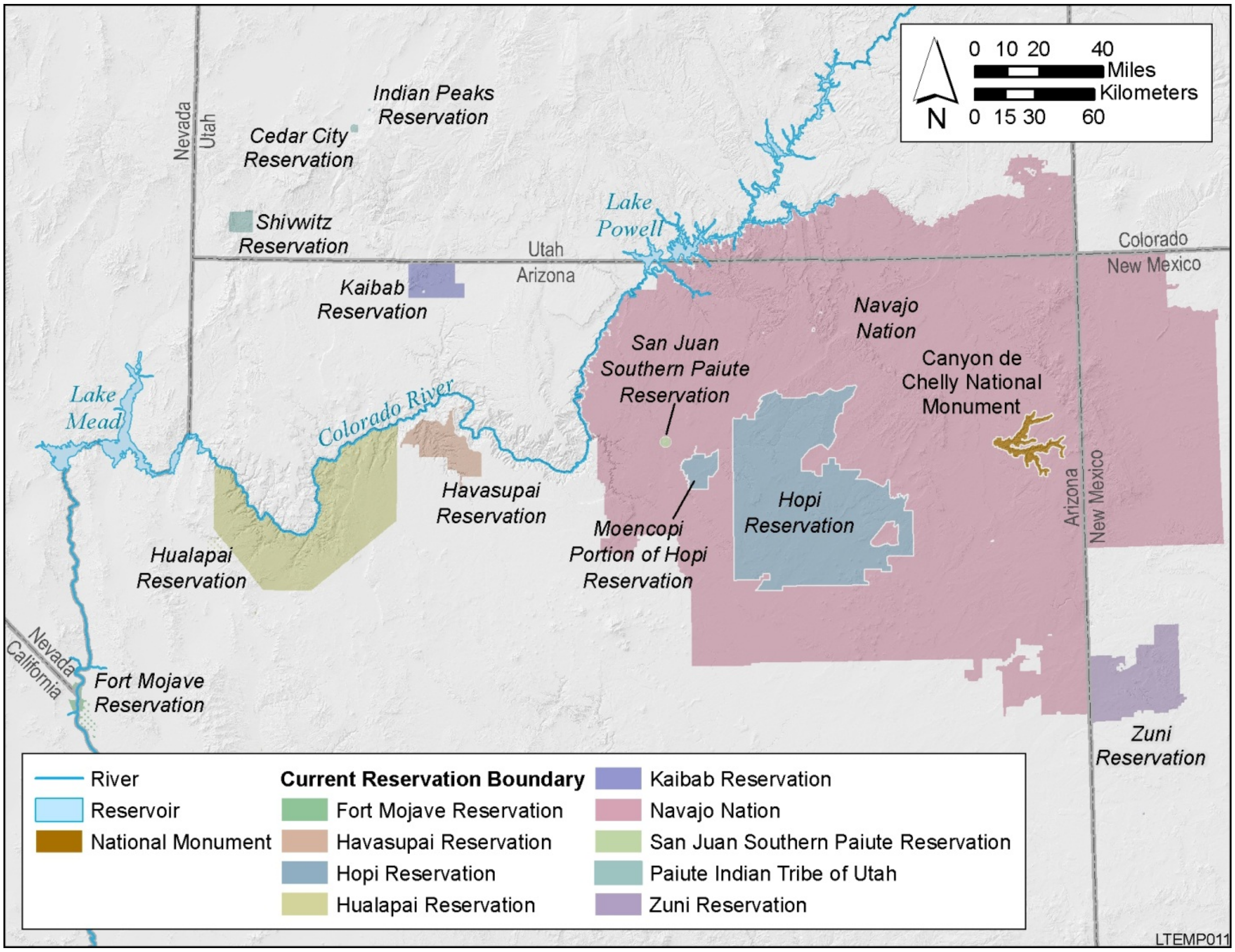

FIGURE 1-4 Indian Reservations within or Adjacent to the LTEMP EIS Project Area

these boundaries. The following sections summarize laws, treaties, and traditional use areas of Tribes with ancestral, spiritual, religious, or economic ties to the project area. These Tribes served as Cooperating Agencies (Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Kaibab Band of Paiute Indians, and Pueblo of Zuni) or a consulting Tribe (Fort Mojave). Tribal connections to resources in and around the Colorado River and the canyons are described in Chapter 3.

1.8.5.1 Fort Mojave Tribe

The Fort Mojave Indian Reservation was established through the Executive Orders of December 1, 1910, and February 2, 1911. The reservation is located along the Colorado River, near Needles, California, and encompasses 42,000 ac covering Mohave County, Arizona; Clark County, Nevada; and San Bernardino County, California (Fort Mojave Indian Tribe 2012).

Traditional Mojave territory encompasses most of the Mojave Desert in the State of California, from the Whipple Mountains, the Turtle Mountains, the Granite Mountains, the Eagle Mountains, the Little San Bernardino Mountains, and the San Bernardino Mountains in the south, west to the San Gabriel and Tehachapi Mountains, north to Granite and Soda Lakes and the Providence Mountains and Paiute Valley in the State of Nevada, to the Black, Buck, and Mojave Mountains to the east in the State of Arizona (CSRI 2002 [U.S. Court of Claims 1950-1960: Docket 283]).

1.8.5.2 Havasupai Tribe

The Havasupai Indian Reservation was established by the Executive Orders of June 8 and November 23, 1880, and March 31, 1882, and expanded by the Act of March 4, 1944 (58 Stat. 110), and the Grand Canyon Enlargement Act (88 Stat. 2089, 1975). In 1975, the Grand Canyon National Park Enlargement Act restored 185,000 ac to the Havasupai Reservation and identified 95,300 ac of traditional use lands within GCNP that were made available for traditional Havasupai practices.

The Havasupai Reservation consists of 188,077 ac of canyon and plateau along the western portion of the Grand Canyon's south rim. Additional traditional use lands are located within GCNP north of the reservation from the plateau to the Colorado River and extend from approximately river mile (RM) 116 to RM 165 (Havasupai 2012).

The Indian Claims Commission determined in 1968 that as of 1880, the Havasupai Tribe exclusively occupied, as their original territory, the land on the Coconino Plateau bounded by the mid-stream of the Colorado River on the north, the Hualapai Reservation on the west, south to the Trinity Mountain, Mount Floyd and easterly to Sitgreaves Mountain, north to Mount Kendricks and along the Little Colorado River on the east to the Colorado River.

The Grand Canyon Enlargement Act of 1975 replaced a portion of the Tribal lands, permitted the traditional uses of park lands, and placed restrictions on the use of portions of the

Havasupai Reservation within GCNP in order to preserve the scenic and natural values of the park (16 USC 228i(b)(7)).

1.8.5.3 Hopi Tribe

The original Hopi Reservation was established by the Executive Order of December 16, 1882, as a 1 × 1 degree latitude/longitude rectangular region. Subsequent partitioning of this original reservation area between the Hopi Tribe and Navajo Nation has resulted in a smaller reservation area, encompassing about 1.5 million ac in parts of Coconino and Navajo Counties, Arizona. There are 11 main Hopi villages within the central portion of the Hopi Reservation and two additional villages located to the west at Moencopi, on a non-contiguous portion of the Hopi Reservation (Figure 1-4).

The Hopi people view their traditional homeland as much larger than the current reservation. It encompasses an area running from near the confluence of the San Juan and Colorado Rivers in the north, southwest to the area of the Havasupai Reservation, southward past Williams and out to the Mogollon Rim in the south, and eastward to the Lupton area on the Arizona–New Mexico border. Even this area is but a small portion of the lands occupied by the ancestors of the Hopi people, which include portions of Colorado, Utah, Arizona, and New Mexico.

1.8.5.4 Hualapai Tribe

The Hualapai Reservation was established by Executive Orders of January 4, 1883; June 2, 1911; May 29, 1912; and July 18, 1913. The reservation encompasses 992,463 ac just south of the Colorado River. The reservation borders the river corridor for approximately 108 mi from approximately RM 164.5 to RM 273.5 (NPS 2006b).

Hualapai traditional territory is bounded by the Colorado River from the Big Bend near Hoover Dam-Lake Mead to the Little Colorado River on the north, the San Francisco Peaks on the east, the Bill Williams and Santa Maria Rivers on the south, and the Colorado River from its confluence with the Bill Williams River to Lake Mead on the west (Reclamation 1995).

1.8.5.5 Navajo Nation

The Navajo Indian Reservation was established by the Treaty of June 1, 1868 (15 Stat. 667). Between 1868 and 1918, various Executive Orders added lands to, or removed lands from, the reservation. The Act of May 25, 1918 (40 Stat. 561, 570), prohibited the creation of, or any additions to, Indian reservations in New Mexico and Arizona “except by Act of Congress.” Congress added land to the Navajo Indian Reservation by the Act of May 23, 1930 (46 Stat. 378), amended by the Act of February 21, 1931 (46 Stat. 378), and the Act of March 1, 1933 (47 Stat. 1418). The Act of June 14, 1934 (48 Stat. 960), describes the exterior boundaries of the 17.6-million-ac reservation in Arizona, subject to various exclusions and conditions set out in the act.

The traditional Navajo homeland, or *Dinetah*, is bounded by four sacred mountains: *Sissnaajinii* (Blanca Peak, near Alamosa, Colorado) on the east; *Tsoo Dzil* (Mount Taylor near Grants, New Mexico) on the south; *Dook' o' oosliid* (San Francisco Peaks near Flagstaff, Arizona) on the west; and *Dibe Ntsaa* (La Plata Mountains near Durango, Colorado) on the north. Traditional use areas extend well beyond this boundary encompassing areas associated with the Little Colorado River, the Colorado River and its tributaries, and alongside the rim. According to Navajo oral tradition, in aboriginal times, Tribal members ranged as far as the Gulf of California. Documented histories were shared during the initial EIS in 1995 from the Navajo Nation Historic Preservation Department (NNHPD), taken from the cultural resources inventory report (Roberts et al. 1995).

1.8.5.6 Pueblo of Zuni

The Zuni Indian Reservation was established by the Executive Orders of March 16, 1877, May 1, 1883, and March 3, 1885, and was expanded by the Proclamation of November 30, 1917 (40 Stat. 1723); the Congressional Act of June 20, 1935 (49 Stat. 393); the Executive Order of August 13, 1949; and the Congressional Act of March 16, 1962 (76 Stat. 33). The Pueblo of Zuni is located approximately 150 mi west of Albuquerque, New Mexico, and encompasses approximately 450,000 ac (Pueblo of Zuni 2013). In addition to the lands established by Executive Orders and Presidential proclamation, two additional non-contiguous areas are included in the Zuni Reservation: the Zuni Salt Lake (1 mi^2) added in 1978 and Kolhu'wala:wa (Zuni Heaven) in Arizona consisting of 14 mi^2 added on August 28, 1984.

The traditional territory of the Zuni Tribe is bounded by the San Francisco Peaks on the northwest corner and by portions of the Little Colorado River and Pueblo Colorado Wash on the far northern boundary. The view of Pueblo of Zuni is that traditional use extends considerably beyond the traditional territorial boundaries and includes GCNP and GCNRA (Reclamation 1995; Dongoske 2012). It also should be noted that the Zunis are considered an Indian Tribe of Arizona.

1.8.5.7 Southern Paiute Tribes

The Southern Paiute Tribes that have ties to the region and who are most directly tied to the project area include the Kaibab Band of Paiute Indians; the Paiute Indian Tribe of Utah, which consists of five bands of Southern Paiute (Cedar Band, Indian Peaks Band, Kanosh Band, Koosharem Band, and Shivwits Band); and the San Juan Southern Paiute. The Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah are also members of the Southern Paiute Consortium. The Kaibab Band represents the consortium in matters pertaining to Glen Canyon Dam and Colorado River management, and served as a Cooperating Agency on the LTEMP EIS.

The Kaibab Band of Paiute Indians Reservation was established by the Executive Orders of June 11, 1913, and July 17, 1917. The reservation is located approximately 50 mi north of the Grand Canyon. The reservation encompasses approximately 121,000 ac and includes five Tribal villages and two non-Indian communities (Kaibab Paiute 2013).

The Paiute Indian Tribe of Utah Reservation was established on April 3, 1980, by an Act of Congress (94 Stat. 317, 1980) and consists of 10 separate land parcels located in 4 southwestern Utah counties, covering 33,709 ac (PITU 2013).

The San Juan Southern Paiute were given 5,400 ac of land within the Navajo Reservation boundary when their leaders signed a treaty with the Navajo Nation on May 20, 2000. Approximately 5,100 ac of this land is located near Tuba City, Arizona, with the remaining 300 ac located just south of Lake Powell (NPS 2013d).

The traditional lands of the Southern Paiute people are bounded by more than 600 mi of the Colorado River, extending from the Kaiparowits Plateau in southern Utah to Blythe, California (Bulletts et al. 2012). These lands extend from the Colorado River northward, inclusive of the Grand and Glen Canyons, into Beaver County, Utah, and from the Escalante River drainage on the east within GCNRA to Death Valley on the west, including the Virgin River drainage, the Muddy River drainage, and the area around present-day Las Vegas, Nevada (ICC 1965).

1.9 LAWS AND REGULATIONS RELATED TO OPERATIONS OF GLEN CANYON DAM AND PARK MANAGEMENT

The following lists of laws, regulations, and treaties are presented here to provide context for the management of the Colorado River because they must be complied with for operation of Glen Canyon Dam and for park management, and may or may not specifically apply to this action. Nothing in this EIS is intended to interpret the authorities listed below.

1.9.1 Environmental Laws and Executive Orders

- Bald and Golden Eagle Protection Act of 1940, as amended 1962 (16 USC 668c)
- Clean Air Act of 1970 (33 USC 1251 et seq.)
- Clean Water Act of 1972 (33 USC 1251 et seq.)
- Endangered Species Act of 1973 (16 USC 1531–1544, 87 Stat. 884)
- E.O. 11514, “Protection and Enhancement of Environmental Quality,” as amended by E.O. 11991, “Relating to Protection and Enhancement of Environmental Quality” (U.S. President 1970)

- E.O. 11988, "Floodplain Management" (U.S. President 1977a)
- E.O. 11990, "Protection of Wetlands" (U.S. President 1977b)
- E.O. 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" (U.S. President 1994b)
- E.O. 13112, "Invasive Species" (U.S. President 1999)
- E.O. 13186, "Responsibilities of Federal Agencies to Protect Migratory Birds" (U.S. President 2001)
- Fish and Wildlife Coordination Act of 1934 (16 USC 661 et seq.)
- The Grand Canyon Protection Act of 1992 (P.L. 102-575)
- Migratory Bird Treaty Act of 1918, as amended 2008 (16 USC 703)
- National Environmental Policy Act of 1969, as amended (42 USC 4321 et seq.)
- National Park Service Organic Act of 1916 (16 USC 1–4, 22, and 43, as amended)
- Redwoods National Park Expansion Act of 1978 (Redwoods Amendment) (16 USC 1a-1)
- Wild and Scenic Rivers Act of 1968 (16 USC 1271 et seq.)
- Wilderness Act of 1964 (16 USC 1131–1136)

1.9.2 Cultural/Historical Laws and Executive Orders

- Antiquities Act of 1906 (16 USC 431–433)
- Archaeological and Historic Preservation Act of 1974 (16 USC 469 et seq.)
- Archaeological Resources Protection Act of 1979 (16 USC 470 et seq., P.L. 96-95)
- E.O. 11593, "Protection and Enhancement of the Cultural Environment" (U.S. President 1971)
- Historic Sites, Buildings, and Antiquities Act of 1935 (16 USC 461 et seq., as amended by P.L. 89-249)

- National Historic Preservation Act of 1966 (54 USC 300101 et seq., P.L. 89-665)

1.9.3 American Indian and Tribal Consultation Laws and Executive Orders

- American Indian Religious Freedom Act of 1978 (P.L. 95-431, 92 Stat. 469, 42 USC 1996)
- E.O. 13007, "Indian Sacred Sites" (U.S. President 1996)
- E.O. 13175, "Consultation and Coordination with Indian Tribal Governments" (U.S. President 2000)
- Native American Graves Protection and Repatriation Act of 1990 (P.L. 101-601, 104 Stat. 3048, 25 USC 3001 et seq.)

1.9.4 Laws Establishing Criteria Related to Power Marketing

- Colorado River Storage Project Act of 1956 (P.L. 84-485, 70 Stat. 105)
- Department of Energy Organization Act of 1977 (P.L. 95-91, 91 Stat. 565, 42 USC 7101)
- Flood Control Act of 1944 (P.L. 78-534, 58 Stat. 887)
- Reclamation Project Act of 1939 (P.L. 76-260, 53 Stat. 1187, 43 USC 485)

1.9.5 Law of the River

The treaties, compacts, decrees, statutes, regulations, contracts, and other legal documents and agreements applicable to the allocation, appropriation, development, exportation, and management of the waters of the Colorado River Basin are often referred to as the Law of the River. There is no single, universally agreed upon definition of the Law of the River, but it is useful as a shorthand reference to describe this longstanding and complex body of legal agreements governing the Colorado River. Documents generally considered to be part of the Law of the River include those listed in Table 1-2.

1.10 RELATED ACTIONS

Numerous ongoing and completed plans, policies, actions, and initiatives are related to the operation of the Glen Canyon Dam and Colorado River with respect to the proposed federal action analyzed in this EIS. Reclamation and NPS have identified documents that would assist

TABLE 1-2 Selected Documents Included in the Law of the River[a]

1899	The Rivers and Harbors Act (Mar. 3)
1902	The Reclamation Act (Jun. 17)
1904	Reclamation of Indian Lands in Yuma, Colorado River and Pyramid Lake Indian Reservations Act (Apr. 21)
1904	Yuma Project authorized by the Secretary (May 10), pursuant to Section 4 of the Reclamation Act of June 17, 1902
1910	Warren Act (Feb. 21)
1910	Protection of Property Along the Colorado River Act (Jun. 25)
1912	Patents Act and Water-Right Certificates Act (Aug. 9 and 26)
1917	Yuma Auxiliary Project Act (Jan. 25)
1918	Availability of Money for Yuma Auxiliary Project Act (Feb. 11)
1920	Sale of Water for Miscellaneous Purposes Act (Feb. 25)
1920	Federal Power Act (Jun. 10)
1922	The Colorado River Compact (Nov. 24)
1925 *(1927–1946)*	The Colorado River Front Work Act (Mar. 3) and Levee System Acts (Jan. 21, 1927–Jun. 28, 1946)
1928	The Boulder Canyon Project Act (Dec. 21)
1929	The California Limitation Act (Mar. 4)
1931	The California Seven Party Agreement (Aug. 18)
1935	The Parker and Grand Coulee Dams Authorization (Aug. 30)
1939	The Parker Dam Power Project Appropriation Act (May 2)
1939	The Reclamation Project Act (Aug. 4)
1940	The Boulder Canyon Project Adjustment Act (Jul. 19)
1944	The Flood Control Act (Dec. 22)
1944	The Mexican Water Treaty (Feb. 3); subsequent minutes of the International Boundary and Water Commission
1947	Gila Project Act (Jul. 30)
1948	The Upper Colorado River Basin Compact (Oct. 11)
1954	Consolidated Parker Dam Power Project and Davis Dam Project Act (May 28)
1954	Palo Verde Diversion Dam Act (Aug. 31)
1956	Change Boundaries, Yuma Auxiliary Project Act (Feb. 15)
1956	The Colorado River Storage Project Act (Apr. 11)
1958	Water Supply Act (Jul. 3)
1958	Boulder City Act (Sept. 2)
1960	Report of the Special Master, Simon H. Rifkind, *Arizona v. California* (Dec. 5)
1964	International Flood Control Measures, Lower Colorado River Act (Aug. 10)
1965	Southern Nevada (Robert B. Griffith) Water Project Act (Oct. 22)
1968	The Colorado River Basin Project Act (Sept. 30)
1970 *(2005)*	Criteria for the Coordinated Long Range Operation of Colorado River Reservoirs (Jun. 8), amended Mar. 21, 2005
1970	Supplemental Irrigation Facilities, Yuma Division Act (Sept. 25)
1972	43 CFR Part 417 Lower Basin Water Conservation Measures (Sept. 7)
1974	The Colorado River Basin Salinity Control Act (Jun. 24)
1984	Hoover Power Plant Act (Aug. 17)
1991	Reclamation States Emergency Drought Relief Act
1992	Grand Canyon Protection Act (Oct. 30)
1999	Offstream Storage of Colorado River Water and Development and Release of Intentionally Created Unused Apportionment in the Lower Division States (Nov. 1) (Reclamation 1999a)
2003	Colorado River Water Delivery Agreement (Oct. 10)
2006	The Consolidated Decree entered by the U.S. Supreme Court in *Arizona v. California* (1964)
2007	Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead

[a] Years in italics indicate amendments or related actions.

Source: Reclamation (2007b).

the reader in understanding the issues analyzed in this process and underscore the importance of collaboration among agency and stakeholder participants.

1.10.1 Biological Opinions

- Final Biological Opinion for the Proposed Adoption of Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (FWS 2007a).
- Final Biological Opinion on the Operation of Glen Canyon Dam, including High-Flow Experiments and Nonnative Fish Control (FWS 2011c). This replaced former Biological Opinions from 1995 to 2009.
- Final Biological Opinion on the Comprehensive Fisheries Management Plan, Coconino and Mohave Counties, Arizona (FWS 2013a).

1.10.2 Environmental Impact Statements and Related Documents

Operation of Glen Canyon Dam: Environmental Impact Statement and Record of Decision (Reclamation 1996). Glen Canyon Dam currently operates under provisions of the 1996 ROD (Reclamation 1996) for the Glen Canyon Dam EIS (Reclamation 1995). The Secretary accepted the recommendation of the 1995 EIS and signed the 1996 ROD (Reclamation 1996) that selected MLFF as the operating system for the dam. The flow parameters of MLFF are presented in Section 1.8.3 of this EIS.

A component of the final Glen Canyon Dam EIS (Reclamation 1995) and the environmental commitments identified in the 1996 ROD (Reclamation 1996) was the implementation of a Programmatic Agreement regarding operations of the Glen Canyon Dam. This agreement, along with subsequent monitoring and remedial action plans and the 2007 Comprehensive Treatment Plan, set a strategy for long-term management of archaeological sites affected by the operations of Glen Canyon Dam. In addition, separate, action-specific Memoranda of Agreement were established among the signatories to the agreements, primarily Reclamation, NPS, Arizona State Historic Preservation Office, and affiliated Tribes for actions related to the High Flow Experimental Protocol EA (Reclamation 2011b) and the Nonnative Fish Control EA (Reclamation 2011a).

Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007b). In 2005, spurred by a multi-year drought, decreasing system storage, and growing demands for Colorado River water, the Secretary directed Reclamation to work with the Basin States to develop additional strategies for addressing the coordinated management of the reservoirs of the Colorado River system. In response, Reclamation began to develop and adopt interim operational guidelines that would address the operation of Lake Powell and Lake Mead during drought and low-reservoir conditions. Adopted in 2007, these Interim Guidelines would be used each year (through 2025 for water supply determinations and through 2026 for reservoir operating decisions) in implementing the LROC for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. This ROD did not modify the authority of the Secretary to determine monthly, daily, hourly, or instantaneous releases from Glen Canyon Dam.

The completed Interim Guidelines determine the availability of Colorado River water for use in the Lower Basin, on the basis of Lake Mead's water surface elevation, as a way to conserve reservoir storage and provide water users and managers with greater certainty regarding the reduction of water deliveries during drought and other low-reservoir conditions. The Interim Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing releases and conserved amounts on predetermined levels in both reservoirs, which would minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin. In addition, the Interim Guidelines established a mechanism for storing and delivering conserved water from Lake Mead, referred to as Intentionally Created Surplus, intended to minimize the severity and likelihood of potential future shortages. Nothing in this LTEMP EIS is intended to affect, or will affect, future decisions that may be made regarding the implementation of the LROC after the Interim Guidelines expire in 2026.

Colorado River Management Plan: Final Environmental Impact Statement and Record of Decision (NPS 2006a). This Final EIS (NPS 2005a) presents a visitor use management plan for the Colorado River corridor in the Grand Canyon. The ROD (NPS 2006a) was approved in early 2006, and the CRMP were published later in the year (NPS 2006b). The CRMP's section on research, monitoring, and mitigation for the plan focuses on the impacts of visitor use and is a consideration for the LTEMP EIS analysis.

Lower Colorado River Multi-Species Conservation Program—Final Programmatic Environmental Impact Statement/Environmental Impact Report (DOI 2004). This Programmatic EIS evaluates the impacts of implementing the Lower Colorado River Multi-Species Conservation Program Conservation Plan. It is intended to avoid, minimize, and fully mitigate the incidental take of the covered species from the implementation of the covered activities to the maximum extent practicable. The Conservation Plan also is intended to contribute to the recovery of species listed as threatened or endangered under the ESA and reduce the likelihood for future listing of unlisted covered species along the lower Colorado River. The ROD (DOI 2005) was approved in 2005.

General Management Plan for Grand Canyon National Park (NPS 1995). This plan guides the management of resources, visitor use, and general development at the park over a 10- to 15-year period. The primary purpose of the plan is to provide a foundation from which to protect park resources while providing for meaningful visitor experiences. A secondary purpose is to encourage compatible activities on adjacent lands so as to minimize adverse effects on the park.

Backcountry Management Plan, Grand Canyon National Park, Arizona (NPS 1988). This plan defines the primary policies that manage visitor use and resource protection for the undeveloped areas of GCNP. GCNP has started work on a Backcountry Management Plan and EIS. The park's existing Backcountry Management Plan is being updated to comply with current

NPS laws and policies and the park's 1995 General Management Plan. Once completed, the revised Backcountry Management Plan will guide management decisions regarding the park's backcountry and wilderness resources into the future.

Lake Mead National Recreation Area General Management Plan—Final Environmental Impact Statement (NPS 1986). This plan presents short-term and long-term strategies for meeting the management objectives of LMNRA. It addresses resource management, resource use, and park development challenges. The plan was intended to guide park management for 25 years or longer when it was issued. The purpose of the plan is to provide a cohesive framework for management decisions, management proposals, concession planning, and guidance for short-term decision-making.

Glen Canyon National Recreation Area General Management Plan—Final Environmental Impact Statement (NPS 1979). This plan and wilderness recommendation lays out proposals for meeting four levels of management objectives for GCNRA, ranging from general to specific. The first-level objective is to manage GCNRA to maximize its recreational enjoyment. Objective levels 2 through 4 address increasingly specific objectives, including those for cultural, Tribal, mineral, and grazing resources and management of the reservoir. The plan presents a management zoning proposal to divide GCNRA into four management zones: natural, recreation and resource utilization, cultural, and development.

1.10.3 Environmental Assessments and Related Documents

Nonnative Fish Control Environmental Assessment (Reclamation 2011a). In this assessment, Reclamation proposed to conduct research, monitoring, and specific actions to control nonnative fish in the Colorado River downstream from Glen Canyon Dam in an effort to help conserve native fish. The purpose of the action was to minimize the negative impacts of competition and predation on an endangered fish, the humpback chub. The action was needed because competition and predation by nonnative fishes, particularly rainbow trout and brown trout, may be contributing to a reduction in survival and recruitment of young humpback chub and threatening the potential recovery of the species. Rainbow trout and brown trout are not native to the Colorado River Basin and have been introduced into the region as sport fish. The Finding of No Significant Impact (FONSI) (Reclamation 2012b) was signed in May of 2012.

High-Flow Experiment Protocol Environmental Assessment (Reclamation 2011b). This experimental protocol was developed following analysis of a series of high-flow experimental releases. The protocol is intended to improve conservation of limited sediment resources in the Colorado River below Glen Canyon Dam. The FONSI (Reclamation 2012a) was signed in May of 2012.

Environmental Assessment, Comprehensive Fisheries Management Plan for Grand Canyon National Park and Glen Canyon National Recreation Area (NPS 2013e). The NPS is implementing a CFMP, in coordination with the Arizona Game and Fish Department (AZGFD), the FWS, Reclamation, and the USGS GCMRC, for all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam. The intent of the CFMP is to maintain a thriving native fish community within GCNP and a highly valued recreational rainbow trout fishery in the Glen Canyon reach of GCNRA. NPS released a FONSI on December 9, 2013, for the CFMP.

Environmental Assessment and Assessment of Effect, Exotic Plant Management Plan Grand Canyon National Park, Arizona (NPS 2009a). GCNP is using integrated pest management techniques to control and contain exotic plant species within park boundaries. Exotic plant species displace natural vegetation and consequently affect long-term health of native plant and animal communities.

1.10.4 Other Actions, Programs, Plans, and Projects

Additional actions, programs, plans, or projects involving the Colorado River may continue to operate or be contemplated during the life of the LTEMP. These items, which are not directly linked to LTEMP, include:

Colorado River Basin Salinity Control Program (Reclamation 2014c). The Colorado River and its tributaries provide municipal and industrial water to about 27 million people and irrigation water to nearly 4 million ac of land in the United States. The threat of salinity is a major concern in both the United States and Mexico. In June 1974, Congress enacted the Colorado River Basin Salinity Control Act (P.L. 93-320), which directed the Secretary to proceed with a program to enhance and protect the quality of water available in the Colorado River for use in the United States and Republic of Mexico.

Lake Powell Pipeline Project (WCWCD 2012). Washington, Kane, and Iron Counties in Utah are pursuing the construction of a pipeline that would run from Lake Powell, near Glen Canyon Dam, through Kane County, to Sand Hollow Reservoir, which is located approximately 10 mi east of St. George. The pipeline would then run parallel to Interstate 15 into Iron County. The pipeline would be 158 mi long and bring 70,000 ac-ft of water to Washington County, 10,000 ac-ft to Kane County, and 20,000 ac-ft to Iron County.

Final Wilderness Recommendation, Grand Canyon National Park, 2010 Update. The 1980 Final Wilderness Recommendation submitted to the DOI includes 1,143,918 ac proposed for wilderness designation, and includes 26,461 ac as potential wilderness pending the resolution of boundary and motorized boat use issues. The Colorado River was identified as potential wilderness. In 2010, NPS conducted internal reviews and included refinements to the proposed wilderness acreage estimates. All refinements were consistent with the intent of the original document submitted to the DOI in 1980.

Grand Canyon National Park Foundation Statement for Planning and Management (NPS 2010a). The Foundation Statement provides a base for future planning, as required by NPS, to help guide park management. The Foundation Statement summarizes fundamental resources and values critical to maintaining Grand Canyon’s natural, cultural, and experiential value into the future. Because this Foundation Statement is based on laws and policies that define GCNP and its mission, the Statement should remain relatively unchanged.

Glen Canyon National Recreation Area and Rainbow Bridge National Monument Foundation Document for Management and Planning (NPS 2014i). The Foundation Statement provides a base for future planning, as required by NPS, to help guide park management. The Foundation Statement summarizes fundamental resources and values critical to maintaining Glen Canyon and Rainbow Bridge's natural, cultural, and experiential value into the future. Because this Foundation Statement is based on laws and policies that define GCNRA and its mission, the Statement should remain relatively unchanged.

Management and Control of Tamarisk and Other Invasive Vegetation at Backcountry Seeps, Springs, and Tributaries in Grand Canyon National Park (NPS 2008). Grand Canyon National Park's backcountry seeps, springs, and tributaries of the Colorado River are among the most pristine watersheds and desert riparian habitats remaining in the coterminous United States. This report contains the details from the invasive plant control and monitoring efforts completed for one phase (Phase II-B) of the three-phase project. Reports for the previous two phases are also available on the NPS website.

Strategic Plan for Glen Canyon National Recreation Area and Rainbow Bridge National Monument FY2007–FY2011 (NPS 2006c). This 5-year Strategic Plan has been written for GCNRA and Rainbow Bridge National Monument (NM). Because Rainbow Bridge NM is administered by GCNRA, this strategic plan covers both units of the NPS.

Grand Canyon National Park Resource Management Plan (NPS 1997). The purpose of the Resource Management Plan was to provide long-term guidance and direction for the stewardship of the natural, cultural, and recreational resources of GCNP.

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2 DESCRIPTION OF ALTERNATIVES

Seven alternatives, including the No Action Alternative, were developed for consideration in the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Draft Environmental Impact Statement (DEIS). These alternatives were assigned letter designations of A through G, with Alternative A being the No Action Alternative.

Alternative A (the No Action Alternative) represents continued implementation of existing operations and actions as defined by existing agency decisions. The other six "action" alternatives represent various ways in which operations and actions could be modified under an LTEMP. Four of the action alternatives (Alternatives C, D [the preferred alternative], F, and G) were developed by the joint-lead agencies for the DEIS—Bureau of Reclamation (Reclamation) and National Park Service (NPS)—with various levels of participation by other U.S. Department of the Interior (DOI) agencies, including the Bureau of Indian Affairs (BIA), U.S. Fish and Wildlife Service (FWS), and U.S. Geological Survey's (USGS's) Grand Canyon Monitoring and Research Center (GCMRC), Argonne National Laboratory (Argonne), Western Area Power Administration (WAPA), and Arizona Game and Fish Department (AZGFD), and input and comments from Cooperating Agencies and Tribes. Two of the action alternatives were developed and submitted for consideration by two stakeholder organizations, the Colorado River Energy Distributors Association (CREDA; Alternative B) and the Colorado River Basin States Representatives from Arizona, California, Colorado, Utah, Nevada, New Mexico, and Wyoming, and the Upper Colorado River Commission (UCRC) (Basin States; Alternative E) in response to an offer made by the DOI in April 2012 to consider alternatives submitted by Cooperating Agencies and Adaptive Management Working Group (AMWG) members. Grand Canyon Trust and the Irrigation and Electrical Districts Association of Arizona submitted letters with comments on alternatives, but did not submit complete alternative proposals. In instances where the DOI made modifications to alternatives submitted by stakeholders, they are noted in the alternative descriptions below. The general process used to develop alternatives is described in Section 2.1, and characteristics of the alternatives are described in Section 2.2.

Several alternative concepts were identified by the public during scoping for the LTEMP DEIS (Argonne 2012):

- Decommission Glen Canyon Dam
- Fill Lake Mead first
- Grand Canyon first
- Maximum powerplant capacity operations
- Naturally patterned flows
- Run-of-the-river

- Species community and habitat-based alternative
- Stewardship alternative
- 12-year experiment of two steady-flow alternatives
- Year-round steady flows

These concepts were considered by Reclamation and NPS for detailed analysis during the alternative development process. In some cases, these were included as an LTEMP alternative, or elements were incorporated within one of the alternatives. In other cases, the concept was eliminated from consideration or further analysis because it did not meet the purpose, need, or objectives of the proposed action; clearly violated existing laws or regulations; or lacked enough specifics to be developed into a full and unique alternative (Section 2.3).

In addition to these submitted alternative concepts, the public identified a variety of specific elements that should be considered for inclusion in LTEMP DEIS alternatives. These elements were considered for inclusion by the joint-lead agencies as they developed LTEMP alternatives. Elements considered but not analyzed in detail are presented in Section 2.4.

2.1 DEVELOPMENT OF ALTERNATIVES

The alternative development process began with identification of the proposed action (i.e., development of an LTEMP), purpose and need of the LTEMP, and the objectives and resource goals of the LTEMP (Sections 1.1, 1.2, and 1.4, respectively). Once these items were defined, NPS and Reclamation worked to develop a set of alternatives that represented the full range of reasonable experimental and management actions; met the purpose, need, and objectives of the proposed action; and were considered within the constraints of existing laws, regulations, and existing decisions and agreements.

Alternative operations that either used different operational strategies (e.g., consistent monthly release pattern or condition-dependent release pattern) or had different primary objectives (e.g., native fish, sediment, or restoration of a more natural flow pattern) were developed and refined. In developing alternatives for detailed analysis, NPS and Reclamation considered and evaluated concepts identified by the public during scoping, alternatives that had been identified for the cancelled Long-Term Experimental Plan (LTEP) Environmental Impact Statement (EIS), and alternatives that had been identified in several efforts led by the Glen Canyon Dam Adaptive Management Program (GCDAMP) (USGS 2006, 2008).

An “alternative screening tool” was developed by the LTEMP EIS team to aid in the development of alternatives by providing preliminary analysis of alternative concepts; it subsequently helped to identify specific operational characteristics of alternatives (e.g., monthly volumes, daily ranges) that would meet the purpose, need, goals, and objectives of the proposed action. This spreadsheet tool used a set of simple models to produce a screening-level appraisal of the impacts of alternatives on flow, sediment (sand) transport, water temperature, humpback chub (*Gila cypha*) growth, trout recruitment, and hydropower value (generation and capacity).

The screening tool was used primarily for rapid prototyping of alternative concepts and to supplement a full analysis of impacts. It was also used to evaluate potential modifications to Alternative D, after modeling was completed on the effects of alternatives on hourly changes in flow and other resources for the 20-year LTEMP period. The screening tool focused on the effects of monthly, daily, and hourly flow patterns in single years rather than the effects of multiple years. The screening tool produced:

- Daily, monthly, and annual estimates of sediment transport (metric tons/year) based on Figure 4a from Rubin et al. (2002);
- Mean monthly temperature at river mile (RM) 61 (confluence with the Little Colorado River) and RM 225 based on Wright, Anderson et al. (2008);
- Mean monthly and annual total growth rates for humpback chub at RM 61 and 225 based on a growth-temperature regression in Robinson and Childs (2001);
- Annual estimates of trout recruitment based on an empirical relationship developed by Korman et al. (2012);
- Daily, monthly, and annual estimate of hydropower value based on the value of hydropower ($/MWh) at different hours of the day and using a conversion factor for cfs to MWh using information from the GTMax model (Palmer et al. 2007); and
- Annual estimate of hydropower capacity based on the value of power generated by maximum daily flows during the peak power month of August.

Several iterations of preliminary draft alternative concepts developed by NPS and Reclamation were presented to the Cooperating Agencies and other stakeholders in workshops and webinars to explain the alternative development process, describe proposed alternative characteristics, and solicit feedback. Workshops included (1) a facilitated public workshop on April 4 and 5, 2012; (2) Cooperating Agency and Tribal meetings on August 10, 2012; (3) Tribal workshops on March 14, 2013; (4) a stakeholder workshop on August 5–7, 2013; (5) a stakeholder workshop on March 31–April 1, 2014; and (6) a stakeholder webinar on December 3, 2015. There were also monthly calls with Cooperating Agencies that included updates and information exchange related to the alternatives.

Alternative D was identified by the DOI as the preferred alternative in the DEIS, and WAPA, the Basin States, and the National Parks Conservation Association submitted letters of support for this alternative before the DEIS was published. DOI received both positive and negative feedback about this alternative from other stakeholders (see Appendix Q). Alternative D was developed by the DOI based on the results of the analysis of the impacts of the other original set of six alternatives. Alternative D adopted many of the best-performing characteristics of

Alternatives C and E. The effects of operations under these latter two alternatives were first modeled, and the results of that modeling suggested ways in which characteristics of each could be combined and modified to improve performance, reduce impacts, and better meet the purpose, need, and objectives of the LTEMP. The impacts of Alternative D were then evaluated using the same models employed for other alternatives (Section 4.1), and these results served as the basis for the assessments presented in Chapter 4. Subsequent to that modeling, relatively minor modifications were made to Alternative D based on discussions with Cooperating Agencies, and with the support of screening tool analyses.

To aid in the alternative development process, formal decision analysis tools were also used for the LTEMP DEIS. Such tools are useful because the LTEMP concerns the management of a very complex system with many—possibly competing—resources of interest, and it involves uncertainty about the relationships between management strategies and the responses of resources to those strategies. A structured decision analysis process for LTEMP alternative development and evaluation was facilitated by Dr. Michael Runge of the USGS to obtain multiple stakeholder viewpoints. This was accomplished through a series of workshops and webinars involving LTEMP project managers; EIS analysts; technical representatives from FWS, BIA, WAPA, Arizona Department of Water Resources, and AZGFD; and other AMWG stakeholders. See Section 1.7 for additional information on the role of decision analysis in the LTEMP EIS process, and Appendix C for a complete description of the structured decision analysis process as applied to the LTEMP EIS.

2.2 DESCRIPTIONS OF ALTERNATIVES CONSIDERED IN DETAIL

This section describes the seven alternatives considered for detailed analysis in the LTEMP EIS. Operations under all of these alternatives would use only existing dam infrastructure. There are a number of experimental and management actions that would be incorporated into all of the LTEMP alternatives, except where noted:

- High flow releases for sediment conservation. Implementation of high-flow experiments (HFEs) under all alternatives are patterned after the current HFE protocol (Reclamation 2011b), but some alternatives include specific modifications related to the frequency of spring and fall HFEs, the duration of fall HFEs, the triggers for HFEs, and the overall process for implementation of HFEs, including implementation considerations and conditions that would result in discontinuing specific experiments. For Alternative D, the specific components of the HFE protocol that will be followed are provided in Appendix P. Other alternatives would adopt the existing HFE protocol without modification.

- Nonnative fish control actions. Implementation of control actions for nonnative brown and rainbow trout are patterned after those identified in the Nonnative Fish Control Environmental Assessment (EA) (Reclamation 2011a) and Finding of No Significant Impact (FONSI) (Reclamation 2012b), but some alternatives include specific modifications related to the area where control actions would occur, the specific actions to be implemented, and the overall process for implementation of control actions, including implementation considerations and conditions that would result in discontinuing specific experiments. Nonnative fish control actions are not included in Alternative F. For Alternative D, components of the Nonnative Fish Control EA and FONSI were modified and integrated with other actions in a tiered approach to humpback chub conservation. This tiered approach is described in Section 2.2.4.6 and Appendix O. Other alternatives would adopt the Nonnative Fish Control EA and FONSI actions without modification.

- Conservation measures established by FWS in previous Biological Opinions (BOs). Conservation measures identified in the 2011 BO on operations of Glen Canyon Dam (FWS 2011c) included the establishment of a humpback chub refuge, evaluation of the suitability of habitat in the lower Grand Canyon for the razorback sucker (*Xyrauchen texanus*), and establishment of an augmentation program for the razorback sucker, if appropriate. Other measures include humpback chub translocation; Bright Angel Creek brown trout control; Kanab ambersnail (*Oxyloma haydeni kanabensis*) monitoring; determination of the feasibility of flow options to control trout, including increasing daily down-ramp rates to strand or displace age-0 trout, and high flow followed by low flow to strand or displace age-0 trout; assessments of the effects of actions on humpback chub populations; sediment research to determine effects of equalization flows; and Asian tapeworm (*Bothriocephalus acheilognathi*) monitoring. Most of these conservation measures are ongoing and are elements of existing management practices (e.g., brown trout control, humpback chub translocation, and sediment research to determine the effects of equalization flows), while others are being considered for further action under the LTEMP (e.g., trout management flows [TMFs]). Additional conservation measures were developed for the preferred alternative during Endangered Species Act (ESA) Section 7 consultation with the FWS. These additional conservation measures are described in Appendix O. Other alternatives would adopt the existing conservation measures without modification.

- Non-flow experimental and management actions at specific sites such as nonnative plant removal, revegetation with native species, and mitigation at specific and appropriate cultural sites. Included are pilot experimental riparian vegetation treatment actions planned by NPS. These actions would also have involvement from Tribes to capture concerns regarding culturally significant native plants, and would provide an opportunity to integrate Traditional Ecological Knowledge in a more applied manner into the long-term program.

- Preservation of historic properties through a program of research, monitoring, and mitigation to address erosion and preservation of archeological and ethnographic sites and minimize loss of integrity at *National Register* historic properties.

- Continued adaptive management under the GCDAMP, including a research and monitoring component, as more fully discussed in Section 1.6.

With operational flows limited to 45,000 cfs and below, the overall extent of the riparian area in Grand Canyon is expected to continue to decrease, primarily as a result of continuing lack of water in the old high water zone and continued declines at the upper edges of the new high water zone; however, the vegetation density within the riparian area is expected to continue to increase. Nonnative vegetation and monoculture species such as arrowweed are expected to continue to increase, and key native species (e.g., Goodding's willow) are expected to continue to decrease.

Experimental riparian vegetation treatment activities would be implemented by NPS under all alternatives except for Alternative A and would modify the cover and distribution of riparian plant communities along the Colorado River. All activities would be consistent with NPS Management Policies (NPS 2006d) and would occur only within the Colorado River Ecosystem in areas that are influenced by dam operations. NPS will work with Tribal partners and GCMRC to experimentally implement and evaluate a number of vegetation control and native replanting activities on the riparian vegetation within the Colorado River Ecosystem in Grand Canyon National Park (GCNP) and Grand Canyon National Recreation Area (GCNRA). These activities would include ongoing monitoring and removal of selected nonnative plants, species in the corridor, systematic removal of nonnative vegetation at targeted sites, and native replanting at targeted sites and subreaches, which may include complete removal of tamarisk (both live and dead) and revegetation with native vegetation. Treatments would fall into two broad categories, including the control of nonnative plant species and revegetation with native plant species. Principal elements of this experimental riparian vegetation proposal include:

- Control nonnative plant species affected by dam operations, including tamarisk and other highly invasive species;

- Develop native plant materials for replanting through partnerships and the use of regional greenhouses;

- Replant native plant species to priority sites along the river corridor, including native species of interest to Tribes;

- Remove vegetation encroaching on campsites;

- Manage vegetation to assist with cultural site protection.

None of the alternatives include specific experimental tests or condition-dependent treatments for historic site preservation or Tribal cultural properties and resources other than operations and treatments intended to build and retain sandbars and targeted experimental vegetation actions in relation to cultural sites as described above. Continued evaluation of site stability and integrity would be undertaken as well as continued sediment evaluations, including those related to HFEs. Similarly, NPS's continued evaluation of Traditional Cultural Properties and resources of cultural concern would be evaluated in consultation with traditional practitioners and knowledgeable Tribal scholars. Mitigation would be undertaken to address resource impacts as determined necessary in consultation with Tribes.

In addition to these common elements, there are recent plans and decisions of the joint-lead agencies and DOI-identified management actions that could be implemented under all alternatives (Section 1.10.2). The Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a), together with existing laws and regulations, were used to establish "sideboards" that constrain the breadth and nature of flow and non-flow actions that were considered in the LTEMP alternatives.

Under all alternatives, release patterns could be adjusted to provide ancillary services, including regulation and reserves for hydropower. Regulation is the minute-by-minute changes in generation needed to maintain a constant voltage within a power control area. Regulation affects instantaneous operations that deviate above and below the mean hourly flow without affecting mean hourly flow. Spinning reserves in the control area served by the Colorado River Storage Project are typically provided by power resources in the Aspinall Unit, a series of three hydropower dams on the Gunnison River. However, under rare hydrological and power resource conditions, Aspinall power resources cannot provide spinning reserves. When this occurs, the spinning reserve duty is typically placed on the Glen Canyon Dam powerplant. In the event that these reserves are placed on Glen Canyon and at the same time need to be deployed in response to a grid event, such as a system unit outage or downed power line, WAPA would invoke emergency exception criteria and within minutes or less increase the Glen Canyon Dam power generation level up to the spinning reserve requirement. Associated turbine water release rates would increase in tandem with higher power production.

Operations described under any alternative would be altered temporarily to respond to emergencies. The North American Electric Reliability Corporation (NERC) has established guidelines for the emergency operations of interconnected power systems. A number of these guidelines apply to Glen Canyon Dam operations. These changes in operations would be of short duration (usually less than 4 hr) and would be the result of emergencies within the interconnected electrical system. Examples of system emergencies include insufficient generating capacity; transmission system overload, voltage control, and frequency; system restoration; and humanitarian situations (search and rescue).

The original Notice of Intent to prepare the LTEMP EIS identified the need to determine whether to establish a recovery implementation program for endangered fish species below Glen Canyon Dam. The LTEMP team finds that identifying the need to determine whether to establish a recovery implementation program (RIP) for endangered fish species below Glen Canyon Dam does not meet the purpose and need for the action (Section 1.2). This decision does not preclude the implementation of a RIP for endangered fish species below Glen Canyon Dam in the future. Although the GCDAMP has undertaken a number of actions that have previously been identified as necessary for the recovery of humpback chub in FWS recovery planning documents, the emphasis of that program is on mitigation and conservation actions specified in the National Environmental Policy Act (NEPA) and ESA Section 7 BOs for federal actions—not on the endangered fish species' overall needs to reach recovery.

Specific details of each of the LTEMP alternatives are described in Sections 2.2.1 to 2.2.7. Operational characteristics of LTEMP alternatives are presented in Table 2-1, and condition-dependent and experimental elements are summarized in Table 2-2. In the descriptions below, typical monthly flow patterns, including the mean, minimum, and maximum daily flows, are presented for each alternative in years with an annual release volume of 8.23 million ac-ft (maf). It is known that a wide range of hydrologic conditions will occur over the LTEMP implementation time frame in response to intra-annual and inter-annual variability in basin-wide precipitation cycles. Within a year, monthly operations are typically adjusted (increased or decreased) based on numerous factors. For example, adjustments may be made because of changing annual runoff forecasts, and, since 2007, application of the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a). To model each LTEMP alternative, reservoir operation rules that represent how Glen Canyon Dam would be operated under the alternative were developed for a range of hydrologic conditions and equalization requirements.

2.2.1 Alternative A (No Action Alternative)

The Council on Environmental Quality (CEQ) requires inclusion of an "alternative of no action" (Title 40, *Code of Federal Regulations*, Part 1502.14(d) [40 CFR 1502.14(d)]), which serves as a baseline against which the impacts of "action" alternatives can be compared. For the LTEMP EIS, the No Action Alternative (referred to here as Alternative A) represents a situation in which the DOI would not modify existing decisions related to operations. Alternative A represents continued operation of Glen Canyon Dam as guided by the 1996 Record of Decision (ROD) for operations of Glen Canyon Dam: Modified Low Fluctuating Flow (MLFF), as modified by recent DOI decisions, including those specified in the 2007 ROD on Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (until 2026) (Reclamation 2007b), the HFE EA (Reclamation 2011b), and the Nonnative Fish Control EA (Reclamation 2011a) (both expiring in 2020). As is the case for all alternatives, Alternative A also includes implementation of existing and planned NPS management activities, with durations as specified in NPS management documents (see Section 1.10).

Under Alternative A, daily flow fluctuations would continue to be determined according to monthly volume brackets as follows: 5,000 cfs daily range for monthly volumes less than 600 kaf; 6,000 cfs daily range for monthly volumes between 600 kaf and 800 kaf; and 8,000 cfs for monthly volumes greater than 800 kaf. Other operating criteria specified in the 1996 ROD are identified in Table 2-1. Since 1996, operations under the 1996 ROD have typically resulted in higher monthly water volume allocations in the high electrical demand months of December, January, July, and August (Tables 2-1 and 2-3; Figure 2-1); operators have typically targeted releases of slightly above 800 kaf in these high demand months in order to achieve the maximum allowable daily fluctuation range (8,000 cfs). Figure 2-1 shows minimum, mean, and maximum daily flows in an 8.23 maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-2 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative A. Figure 2-3 shows details of hourly flows during a week in July.

TABLE 2-1 Operational Characteristics of LTEMP Alternatives

Elements of Base Operations[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Monthly pattern in release volume	Historic monthly release volumes. Higher volumes in high electric demand months of Dec., Jan., Jul., and Aug.; volume released in Oct.–Dec. = 2.0 maf in ≥ 8.23-maf years and 1.5 maf in years ≤ 7.48 maf	Same as Alternative A	Highest volume in high electric demand months of Dec., Jan., and Jul.; Feb.–Jun. volumes proportional to contract rate of delivery; lower volumes Aug.–Nov.	Comparable to Alternative E, but Aug. and Sep. volume increased, with additional volume taken from Jan.–Jul.; volume released in Oct.–Dec. = 2.0 maf in ≥ 8.23-maf years and 1.5 maf in years ≤ 7.48 maf	Monthly volumes proportional to the contract rate of delivery, but with a targeted reduction in Aug.–Oct. volumes; volume released in Oct.–Dec. = 2.0 maf in ≥ 8.23-maf years and 1.5 maf in years ≤ 7.48 maf	Relative to Alternative A, higher release volumes in Apr.–Jun.; lower volumes in remaining months	Equal monthly volumes, adjusted with changes in runoff forecast
Minimum flows (cfs)	8,000 between 7 a.m. and 7 p.m. 5,000 between 7 p.m. and 7 a.m.	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	5,000	5,000
Maximum non-experimental flows (cfs)[b]	25,000	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Daily range (cfs/24 hr)[c]	5,000 for monthly volumes <600 kaf 6,000 for monthly volumes 600–800 kaf 8,000 for monthly volumes >800 kaf	Dec. and Jan.: 12,000 Feb., Jul., and Aug.: 10,000 Oct., Nov., Mar., Jun., and Sep.: 8,000 Apr. and May: 6,000	Equal to 7 × monthly volume (in kaf) in all months	Equal to 10 × monthly volume (in kaf) in Jun.–Aug., and 9 × monthly volume (in kaf) in other months; daily range not to exceed 8,000 cfs	Equal to 12 × monthly volume (in kaf) in Jun.–Aug., and 10 × monthly volume (in kaf) in other months	0 cfs[d]	0 cfs[d]

TABLE 2-1 (Cont.)

Elements of Base Operations[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Ramp rates (cfs/hr)	4,000 up 1,500 down	4,000 up 4,000 down in Nov.–Mar. 3,000 down in other months	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 1,500 down	4,000 up 1,500 down

[a] Base operations are defined as operations in those years when no condition-dependent or experimental actions are triggered. Examples of experimental actions include HFEs, low summer flows, and TMFs (see Table 2-2).

[b] Maximum flows presented are for normal operations and may be exceeded as necessary for HFEs, emergency operations, and equalization purposes.

[c] Values presented are the normal daily range in mean hourly flow for each alternative. Some variation in instantaneous flows within hours is allowed in all alternatives to accommodate emergency conditions, regulation requirements, and reserve requirements. For several alternatives, reduced fluctuations would be implemented after significant sediment inputs or after HFEs as described in Table 2-2.

[d] Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

TABLE 2-2 Condition-Dependent and Experimental Elements of LTEMP Alternatives

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
High-Flow Experiments (HFEs)								
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement when triggered through 2020 when protocol expires	Implement when triggered during entire LTEMP period, but not to exceed one spring or fall HFE every other year	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period, but no spring HFEs in first 2 years, and no spring HFE in the same water year as an extended-duration (>96 hr) fall HFE	Implement when triggered during entire LTEMP period, except no spring HFEs in first 10 years	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period
Proactive spring HFE in Apr., May, or Jun., with maximum possible 24-hr release up to 45,000 cfs	Trigger: High-volume equalization year (≥10 maf) Objective: To build beaches and protect sand supply otherwise exported by high equalization release	No	No	Yes, if no other spring HFE in same water year	Yes, if no other spring HFE or extended-duration fall HFE in same water year; no proactive spring HFE in first 2 years	No	No	Yes, if no other spring HFE in same water year

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
High-Flow Experiments (HFEs) (Cont.)								
Fall HFE (Oct. or Nov.)	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement when triggered through 2020 when protocol expires	Implement when triggered during entire LTEMP period, but not to exceed one spring or fall HFE every other year	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period
Fall HFEs longer than 96-hr duration	Trigger: Paria River sediment input in fall Objective: Rebuild sandbars	No	No	Yes, but HFE volume limited to that of a 45,000-cfs, 96-hr flow (357,000 ac-ft)	Yes, magnitude (up to 45,000 cfs) and duration (up to 250 hr[b]) dependent on sediment supply; limited to no more than four in a 20-year period	No	No	Yes, magnitude (up to 45,000 cfs) and duration (up to 336 hr) dependent on sediment supply
Adjustments to Base Operations								
Reduced fluctuations before HFEs (“load-following curtailment”)[c]	Trigger: Significant sediment input from Paria River in Dec.–Mar. or Jul.–Oct. Objective: Conserve sediment input for spring or fall HFE	No	No	Yes, in Feb. and Mar. (spring HFE) or Aug.–Oct. (fall HFE)	No	Yes, in Aug.–Oct. (fall HFE)	No change in operations, which already feature steady flows throughout the year	No change in operations, which already feature steady flows throughout the year

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Adjustments to Base Operations (Cont.)								
Reduced fluctuations after HFEs (“load-following curtailment”)[c]	Trigger: HFE Objective: Reduce erosion of newly built sandbars	No	No	Yes, until Dec. 1 after fall HFEs, or May 1 after spring HFEs	No	No	No change in operations, which already feature steady flows throughout the year	No change in operations, which already feature steady flows throughout the year
Low summer flows (Jul., Aug., Sep.)	Trigger: Number of adult humpback chub, temperature at Little Colorado River confluence, and release temperature Objective: Improve recruitment of chub in mainstem	No	No	Test if number of adult chub <7,000, <12°C at Little Colorado River confluence, and release temperature is sufficiently warm to achieve 13°C only if low flows are provided; within-day range 2,000 cfs	Test in second 10 years if release temperature is sufficiently warm to achieve 14°C only if low flows are provided; within-day range 2,000 cfs. If initial test is successful, implement under same conditions when humpback chub population concerns warrant its use.	Test in second 10 years if releases have been cold, number of adult chub ≥7,000, and temperature of at least 16°C can be reached	No change in operations, which already feature low flows during summer	No
Macro-invertebrate production flows	Trigger: None Objective: Increase invertebrate production especially mayflies, stoneflies, and caddisflies	No	No	No	Test, but avoid confounding effects on TMFs. Minimum monthly flow would be held constant on Saturdays and Sundays in May through Aug.	No	No	No

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Adjustments to Base Operations (Cont.)								
Hydropower improvement flows (increased fluctuation levels)	Trigger: Annual volume ≤8.23 maf Objective: Test effect on sediment, humpback chub, and trout	No	Maximum daily flow (held for as long as possible): 25,000 cfs (Dec.–Feb., Jun.–Aug.) 20,000 cfs (Sep.–Nov.) 15,000 cfs (Mar.–May) Minimum daily flow all months: 5,000 cfs Ramp rate up and down: 5,000 cfs/hr Test in 4 years	No	No	No	No	No
Trout Management Actions								
Trout management flows	Trigger: Predicted high trout recruitment in Glen Canyon reach Objective: Improve fishery, reduce emigration to Little Colorado River reach, and subsequent competition and predation on humpback chub	Test	Test and implement if successful	Test and implement if successful; tests in first 5 years not dependent on high trout population	Test and implement if successful; test may be conducted early in the 20-year period even if not triggered by high trout recruitment[d]	2 × 2 factorial design testing with/without HFE and with/without TMFs under warm and cold conditions	No	Test and implement if successful

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Non-Flow Actions								
Tier 1: Expanded translocation of humpback chub within the Little Colorado River	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	No	No	No	Yes	No	No	No
Tier 1: Implement head-start program for larval humpback chub	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	No	No	No	Yes	No	No	No
Mechanical removal of nonnative fish in Little Colorado River reach[e]	Trigger: High trout numbers and low humpback chub numbers in Little Colorado River reach Objective: Increase number of adult and subadult humpback chub	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented until 2020	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period	Trout numbers are above and humpback chub numbers are below Tier 2 triggers in Little Colorado River reach	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period	No	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Non-Flow Actions (Cont.)								
Riparian vegetation treatments	Trigger: None Objective: Improve vegetation conditions at key sites	No	Yes	Yes	Yes	Yes	Yes	Yes

[a] Triggers will be modified as needed during the 20-year LTEMP period in an adaptive manner through processes including ESA consultation and based on the best available science utilizing the experimental framework for each alternative.

[b] The duration of extended-duration HFEs would be increased stepwise; the first test of an extended-duration HFE under Alternative D would be limited to 192 hr; depending on the results of that first test, subsequent durations could be up to 250 hr. Sediment concentration in the river would be monitored during the HFE at least during the first test.

[c] Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

[d] For Alternative D, the decision to conduct TMFs in a given year would consider the resource conditions, as specified in Section 2.2.4.3, and would also involve considerations regarding the efficacy of the test based on those resource conditions.

[e] Trout removal in the Paria River–Badger Rapids reach was assessed in the Nonnative Fish Protocol EA. However, it may not be practical based on the estimated level of effort needed to accomplish significant reductions in numbers of trout in the Little Colorado River reach when trout numbers are high in Marble Canyon (Appendix D in Reclamation 2011a).

TABLE 2-3 Flow Parameters under Alternative A in an 8.23-maf Year[a]

Month	Monthly Release Volume[b] (kaf)	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	600	0.0729	9,758	6,000
November	600	0.0729	10,083	6,000
December	800	0.0972	13,011	8,000
January	800	0.0972	13,011	8,000
February	600	0.0729	10,804	6,000
March	600	0.0729	9,758	6,000
April	600	0.0729	10,083	6,000
May	600	0.0729	9,758	6,000
June	650	0.0790	10,924	6,000
July	850	0.1033	13,824	8,000
August	900	0.1094	14,637	8,000
September	630	0.0765	10,588	6,000

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

Under the current HFE protocol (Reclamation 2011b), high-flow releases may be made in spring (March and April) or fall (October and November). HFE magnitude would range from 31,500 cfs to 45,000 cfs. The duration would range from less than 1 hr to 96 hr. Frequency of HFEs would be determined by tributary sediment inputs, resource conditions, and a decision process carried out by the DOI. The HFE protocol uses a “store and release” approach, in which sediment inputs are tracked over two accounting periods, one for each seasonal HFE: spring (December 1 through June 30) and fall (July 1 through November 30). Implementation of an HFE may require reallocating water from other months in order to maintain at least minimum flows (i.e., 5,000 to 8,000 cfs). The protocol would implement the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling.

One purpose of the HFE protocol is to assess whether multiple, potentially sequential, HFEs conducted under consistent criteria could better conserve sediment resources while not adversely affecting other resources (Reclamation 2011b). The 10-year (2011–2020) experimental period of the protocol provides opportunities for multiple HFEs to be conducted and analyzed. Because necessary sediment and hydrology conditions may not occur every year, the 10-year period increases the likelihood that multiple experiments can be conducted. The protocol incorporates annual resource reviews to provide information that will help to ensure that unacceptable impacts do not occur.

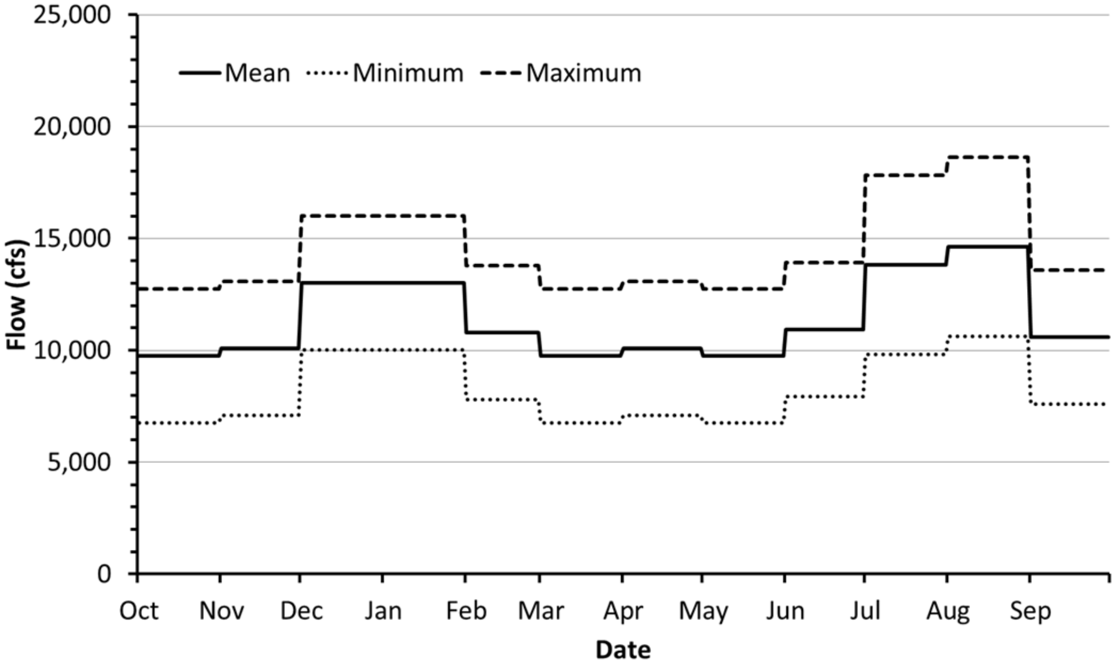

FIGURE 2-1 Mean, Minimum, and Maximum Daily Flows under Alternative A in an 8.23-maf Year Based on Values Presented in Table 2-3

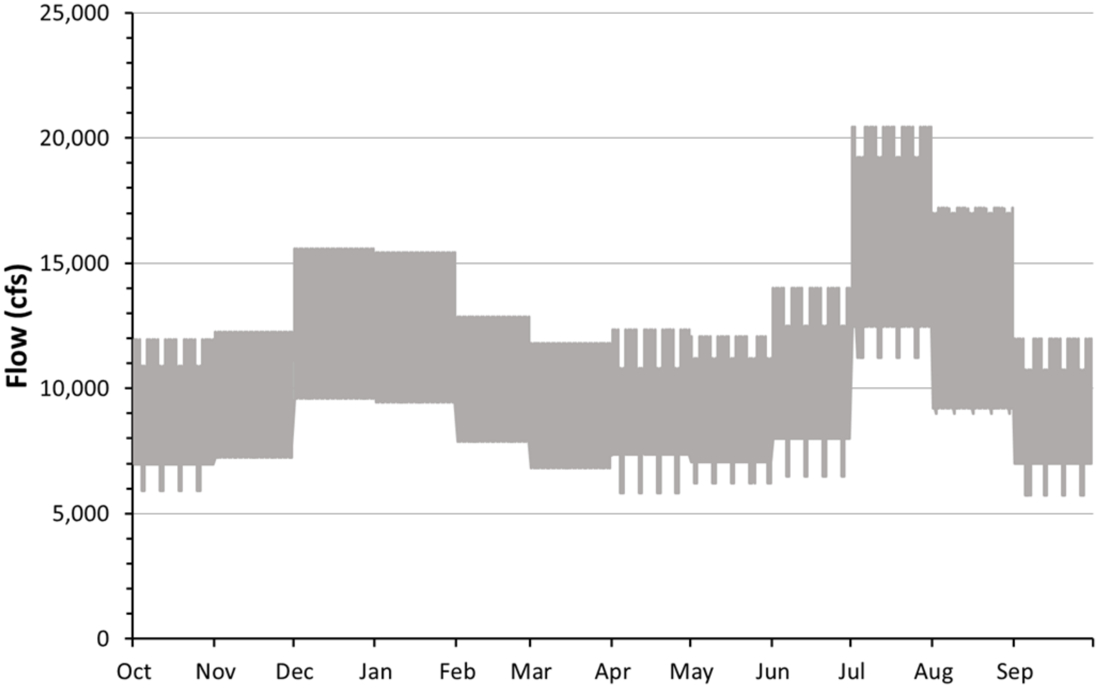

FIGURE 2-2 Simulated Hourly Flows under Alternative A in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-1. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

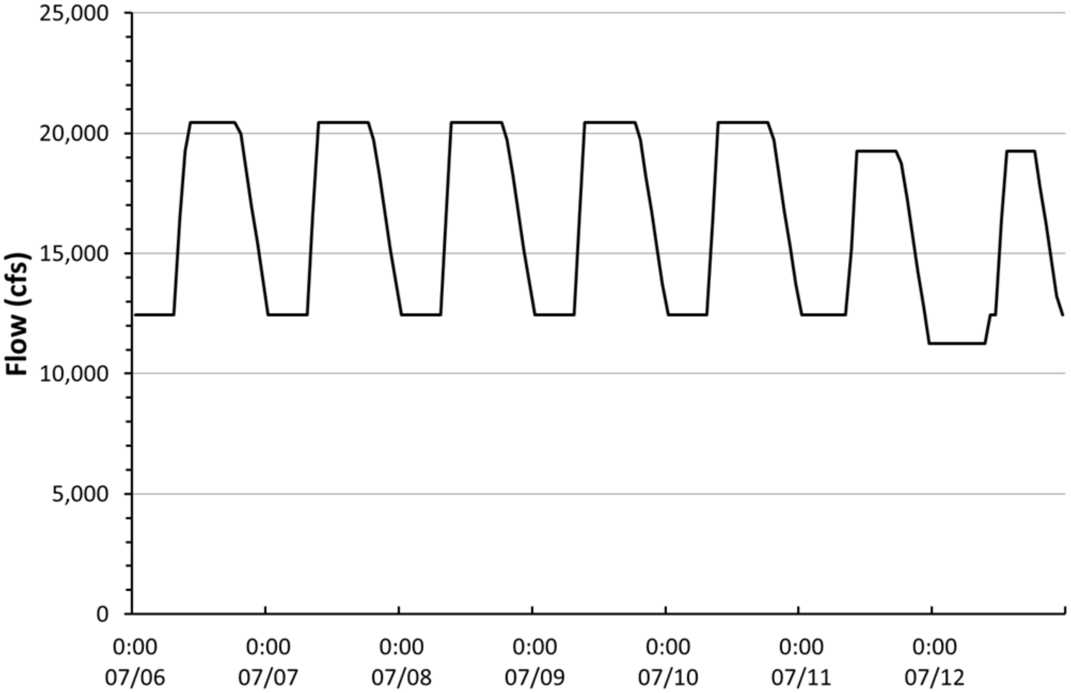

FIGURE 2-3 Simulated Hourly Flows under Alternative A for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

To date, three HFEs have been implemented using the HFE protocol,[1] and they took place on November 18–19, 2012 (24 hr at 42,300 cfs), November 11–16, 2013 (96 hr at 34,100 cfs), and November 10–15, 2014 (96 hr at 37,500 cfs).

Reclamation also recently established a 10-year protocol (to expire in 2020) for trout removal and tests of TMFs (Reclamation 2011a). In part, this protocol was established to coincide with the HFE protocol because there is evidence that HFEs may result in an increase in trout production (Korman, Kaplinski et al. 2011; Melis et al. 2011), which may have negative effects, through competition and predation, on humpback chub. Under the protocol, trout removal may occur in two reaches—the Paria River–Badger Rapids reach (RM 1–RM 8)[2] and the Little Colorado River reach (RM 56–RM 66). The impacts of implementing the protocol were originally described in the Nonnative Fish Control EA (Reclamation 2011a) and are further

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[1] In November 2015, there was sufficient sediment input from the Paria River to support a 96-hr HFE; however, an HFE was not implemented due to concerns that arose after the discovery of the invasive nonnative green sunfish (*Lepomis cyanellus*) in the Glen Canyon reach.

[2] An initial planned test of trout removal in the Paria River–Badger Rapids reach in 2012 was cancelled due to concerns about whirling disease. Removal in the Paria River–Badger Rapids reach may not be practical based on the estimated level of effort needed to accomplish significant reductions in numbers of trout in the Little Colorado River reach when trout numbers are high in Marble Canyon (Appendix D in Reclamation 2011a).

analyzed in this EIS. Mechanical removal would primarily consist of the use of boat-mounted electrofishing equipment to remove all nonnative fish captured. Motorized electrofishing boats would operate during the night over a period of up to 2 weeks, utilizing gas generators to power lights and electrofishing equipment. Captured nonnative fish would be removed alive and potentially stocked into areas that have an approved stocking plan, unless live removal fails, in which case fish would be euthanized and used for later beneficial use (Reclamation 2011a). Since 2011, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters.

Experimental components of Alternative A would be consistent with those that are part of the current program, including those detailed in the HFE and Nonnative Fish Control EAs and those identified as elements potentially common to all alternatives described above.

2.2.2 Alternative B

The objective of Alternative B is to increase hydropower generation while limiting impacts on other resources and relying on flow and non-flow actions to the extent possible to mitigate impacts of higher fluctuations. CREDA submitted this alternative for analysis and consideration in the LTEMP DEIS. The alternative is similar to the “Option A Variation,” which was one of four options developed and evaluated by the GCDAMP and GCMRC in early planning efforts for the LTEP DEIS. Alternative B focuses on non-flow actions and experiments to address sediment resources, nonnative fish control, and native and nonnative fish communities. Alternative B originally included several elements that were determined to be either outside the scope of this EIS, were already part of a previous NEPA process, or were dismissed for other reasons. See Section 2.4 for elements that were considered but dismissed (i.e., sediment augmentation, bubblers in the Lake Powell forebay, bypass tube generators, and sediment check dams).

Under Alternative B, monthly volumes would be the same as under current operations, but daily flow fluctuations would be higher than under current operations in most months (Table 2-4; Figure 2-4). Increases would be greatest in February, which would have an approximately 66% increase in fluctuations over current operations (10,000 cfs versus the current 6,000 cfs range), while December and January would increase fluctuations approximately 50% (12,000 cfs versus the current 8,000 cfs range). Daily flow fluctuations would be increased by approximately 25% in March, June, September, October, and November (8,000 versus 6,000 cfs), and in July and August (10,000 versus 8,000 cfs). Fluctuations would remain unchanged relative to current operations (6,000 cfs) only in April and May (Tables 2-1, 2-2, and 2-4; Figure 2-4). Compared to current operations, the hourly up-ramp rate would remain unchanged at 4,000 cfs/hr, but the hourly down-ramp rate would be increased to 4,000 cfs/hr in November through March and 3,000 cfs/hr in other months. Figure 2-4 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-5 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative B. Figure 2-6 shows details of hourly flows during a week in July.

TABLE 2-4 Flow Parameters under Alternative B in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	600	0.0729	9,758	8,000
November	600	0.0729	10,083	8,000
December	800	0.0972	13,011	12,000
January	800	0.0972	13,011	12,000
February	600	0.0729	10,804	10,000
March	600	0.0729	9,758	8,000
April	600	0.0729	10,083	6,000
May	600	0.0729	9,758	6,000
June	650	0.0790	10,924	8,000
July	850	0.1081	13,824	10,000
August	900	0.1045	14,637	10,000
September	630	0.0765	10,588	8,000

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

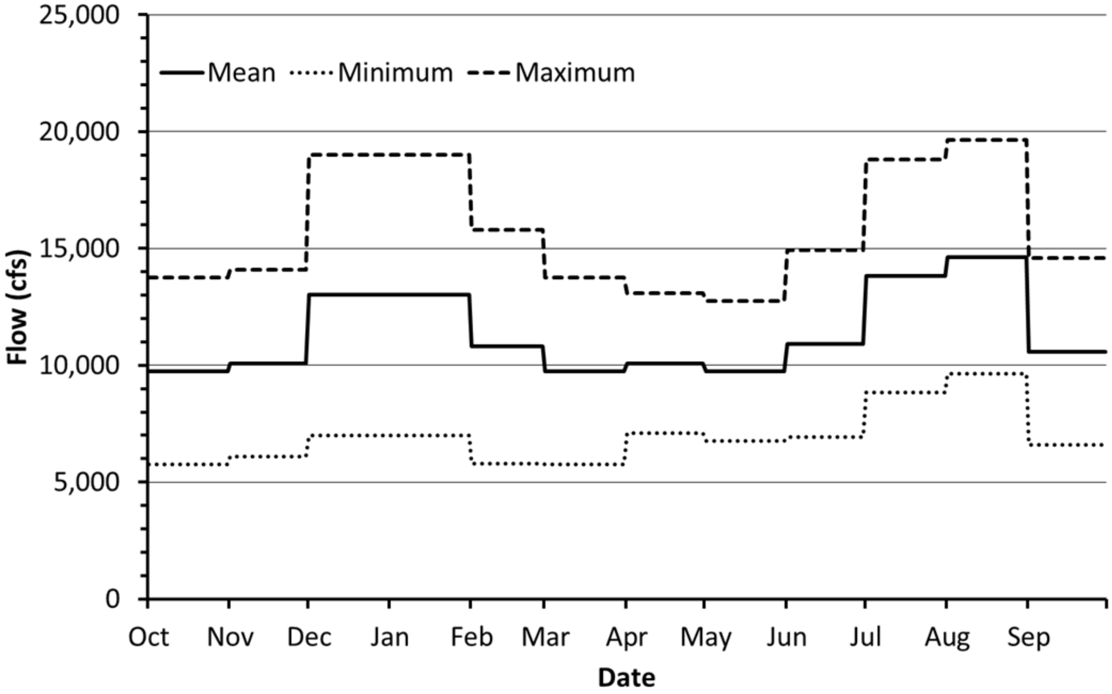


FIGURE 2-4 Mean, Minimum, and Maximum Daily Flows under Alternative B in an 8.23-maf Year Based on Values Presented in Table 2-4

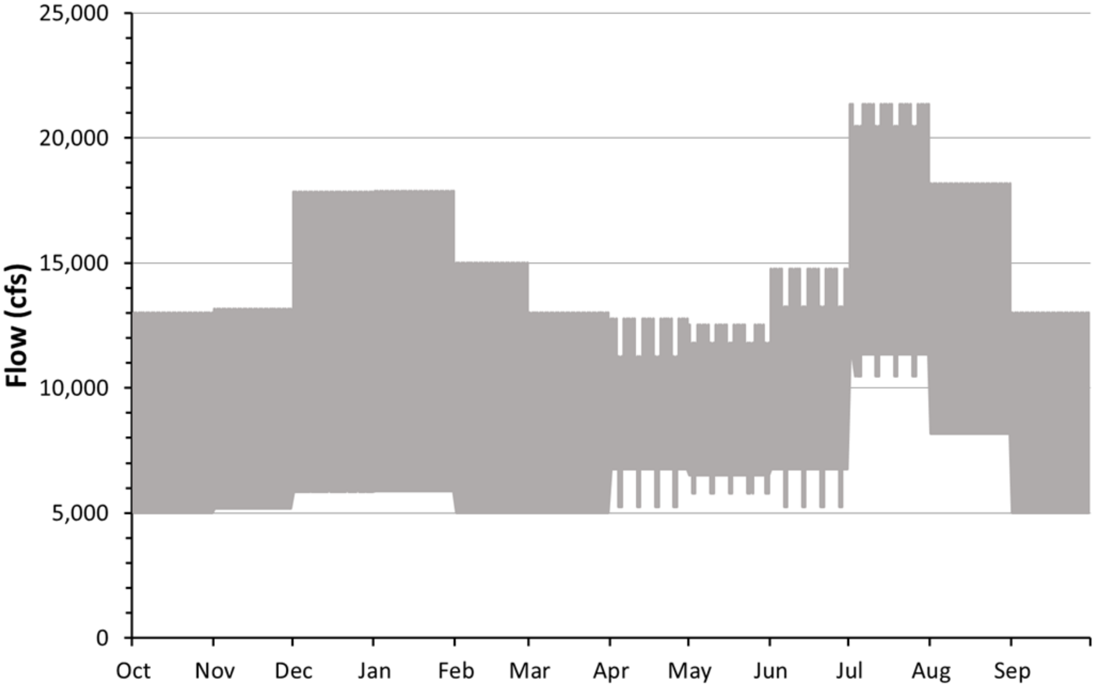


FIGURE 2-5 Simulated Hourly Flows under Alternative B in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-4. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

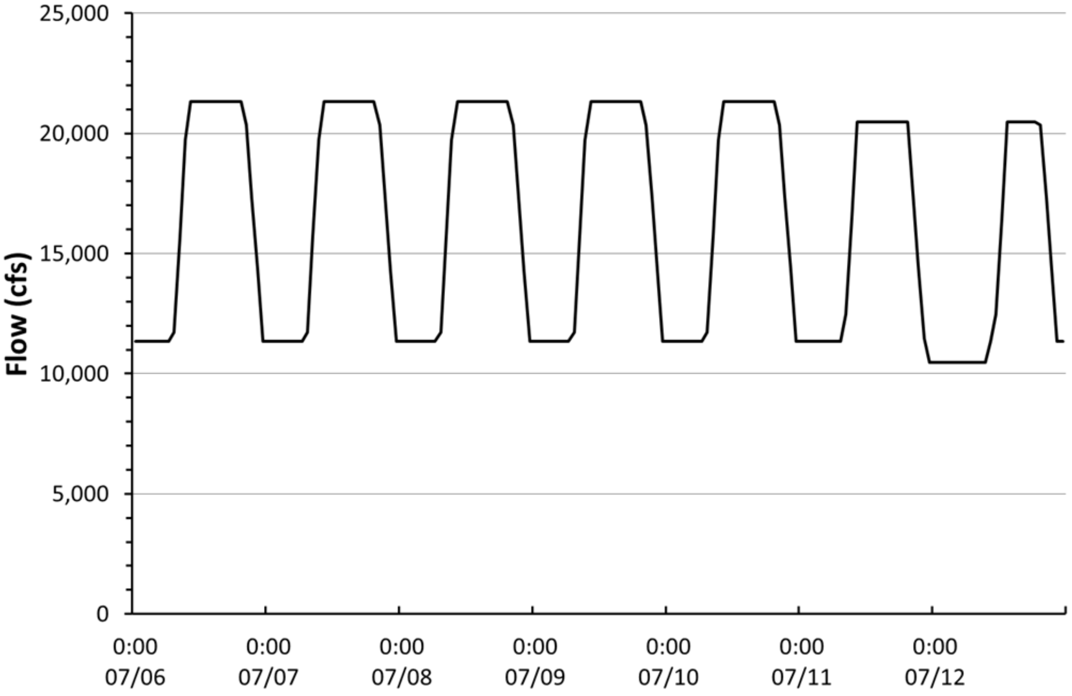


FIGURE 2-6 Simulated Hourly Flows under Alternative B for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

Alternative B includes these elements:

- Implementation of the Nonnative Fish Control protocol (Reclamation 2011a);
- Implementation of the HFE protocol (Reclamation 2011b), but limiting HFEs to a maximum of one every other year;
- Experimental vegetation removal and replanting activities where appropriate.

Experimental components of Alternative B would include those detailed in the HFE and Nonnative Fish Control EAs (Reclamation 2011a,b). Alternative B also includes experiments to analyze specific hypotheses. The specifics of the flows that would be tested in these experiments would be subject to reservoir levels, hydrologic conditions, powerplant maintenance, and economic considerations, and would include the following:

- **TMFs:** TMFs would maintain elevated flows for 2 or 3 days, followed by a very sharp drop in flows to a minimum level for the purpose of reducing annual recruitment of trout. TMFs are described in greater detail in Section 2.2.3.
- **Hydropower improvement experiment:** Alternative B includes testing maximum powerplant capacity releases in up to four years during the LTEMP period, but only in years with annual volumes ≤8.23 maf. Under hydropower improvement flows, within-day releases during the high-demand months of December, January, February, June, July, and August would vary between 5,000 cfs at night and 25,000 cfs during the day; from September through November within-day releases would vary from 5,000 to 20,000 cfs; and from March through May within-day releases would vary from 5,000 to 15,000 cfs (Figures 2-7, 2-8, and 2-9). Up- and down-ramp rates would be 5,000 cfs/hr throughout the year. Years with annual flows ≤8.23 maf typically require firming purchases by WAPA to meet contractual demand; thus, the experiment could mitigate some of those more costly purchases in the high-power months. The experiment is intended to evaluate the effects of maximum powerplant operations on critical resources in the Colorado River Ecosystem.

Under Alternative B, experimental treatments would be implemented as soon as feasible during the LTEMP period. Using this approach, experimental treatments would be implemented at the initiation of the LTEMP period, and they would be eliminated or retained based on their success in providing resource benefits and avoiding adverse resource impacts.

2.2.3 Alternative C

The objective of Alternative C is to adaptively operate Glen Canyon Dam to achieve a balance of resource objectives with priorities placed on humpback chub, sediment, and minimizing impacts on hydropower. Alternative C features a number of condition-dependent

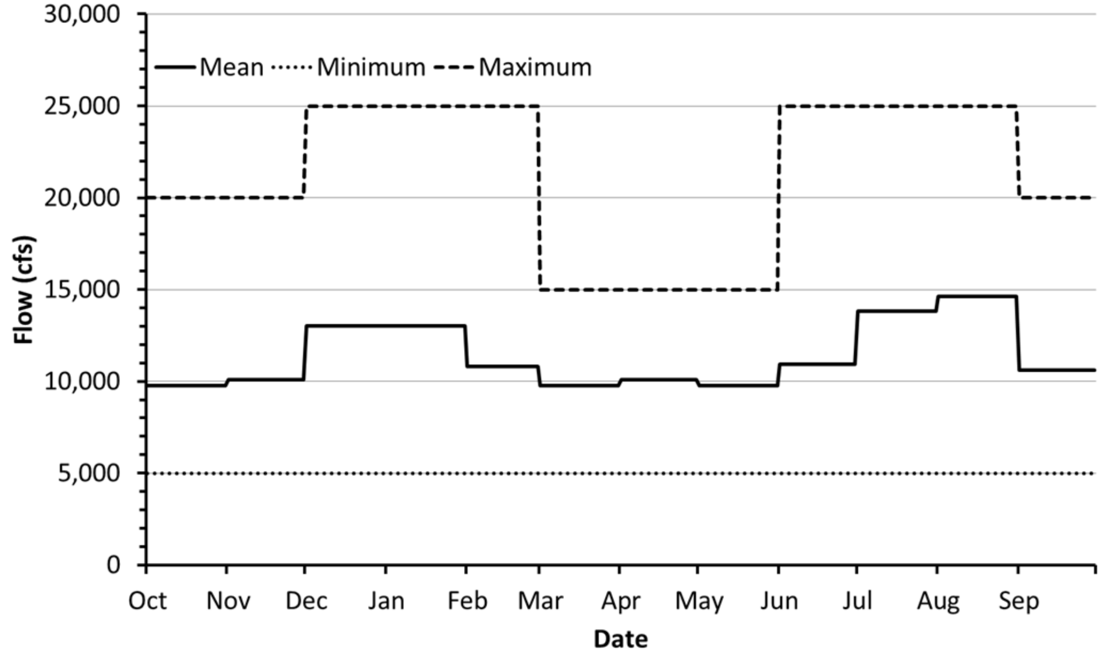


FIGURE 2-7 Example Mean, Minimum, and Maximum Daily Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year

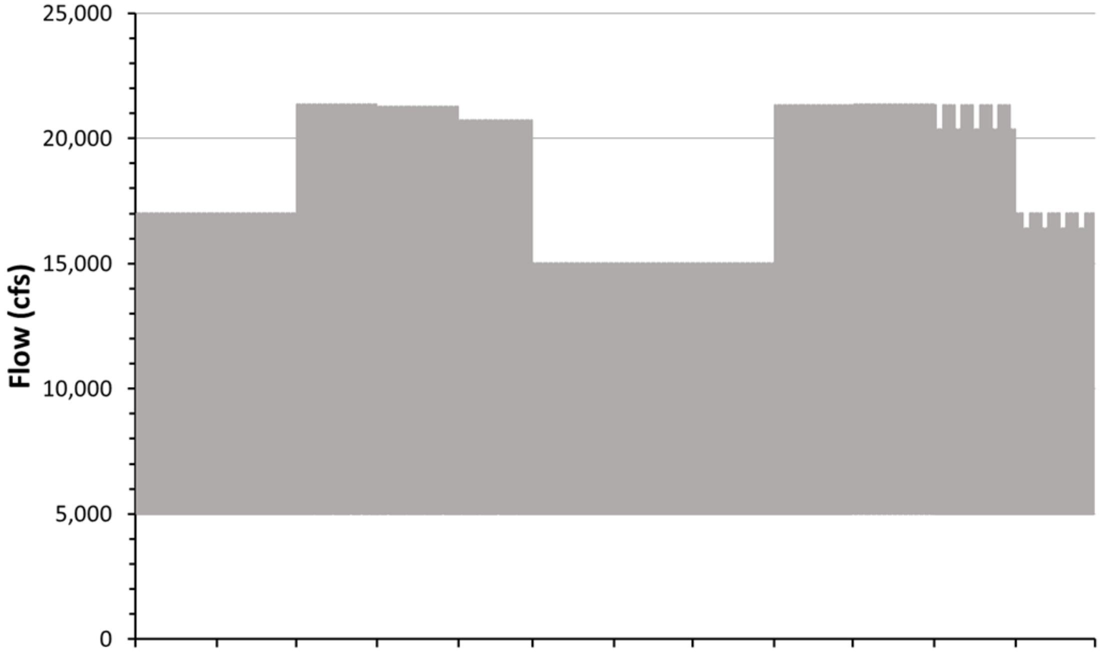


FIGURE 2-8 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-7. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

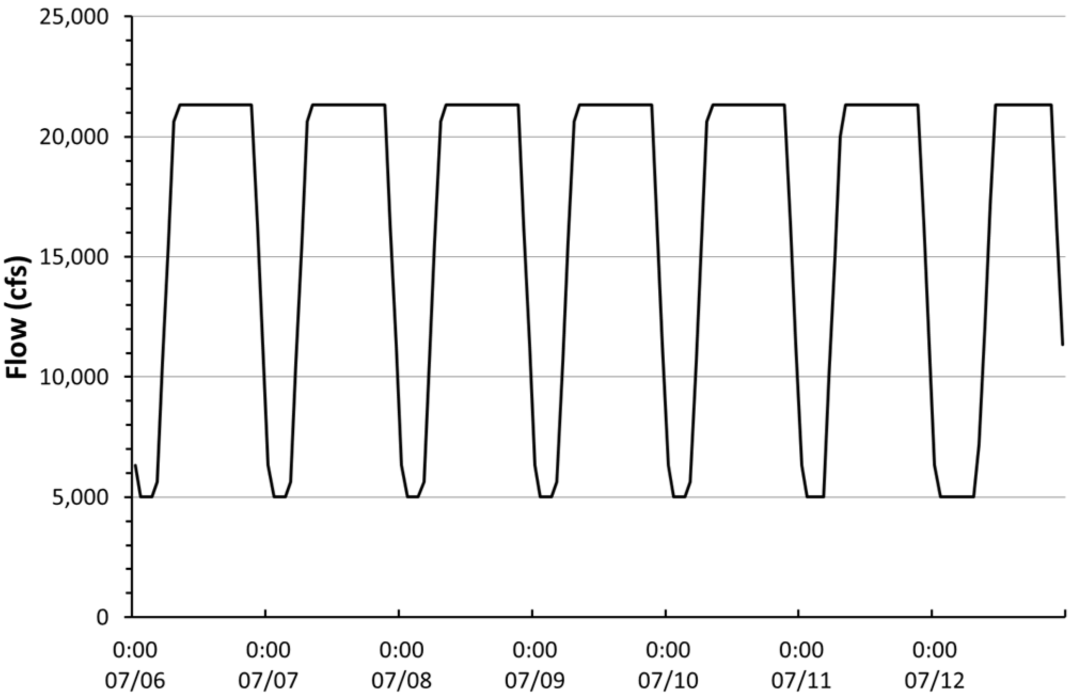


FIGURE 2-9 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B for a Week in July in an 8.23-maf Year (The week starts on Monday and ends on Sunday.)

flow and non-flow actions that would be triggered by resource conditions (Table 2-2). The alternative uses decision trees to identify when a change in base operations or some other planned action is needed to protect resources. Operational changes or implementation of non-flow actions could be triggered by changes in sediment input, humpback chub numbers and population structure, trout numbers, and water temperature.

2.2.3.1 Base Operations under Alternative C

Under base operations of Alternative C, monthly release volumes in August through November would be lower than those under most other alternatives to reduce sediment transport rates during the monsoon period. Release volumes in the high power demand months of December, January, and July would be increased to compensate for water not released in August through November, and volumes in February through June would be patterned to follow the monthly hydropower demand as defined by the contract rate of delivery (Tables 2-1 and 2-5; Figure 2-10).

TABLE 2-5 Flow Parameters under Alternative C in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	480	0.0583	7,806	3,360
November	480	0.0583	8,067	3,360
December	830	0.1009	13,499	5,810
January	830	0.1009	13,499	5,810
February	730	0.0887	13,148	5,111
March	771	0.0937	12,539	5,397
April	686	0.0833	11,524	4,800
May	710	0.0863	11,551	4,972
June	743	0.0903	12,485	5,200
July	830	0.1009	13,499	5,810
August	660	0.0802	10,734	4,620
September	480	0.0583	8,067	3,360

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

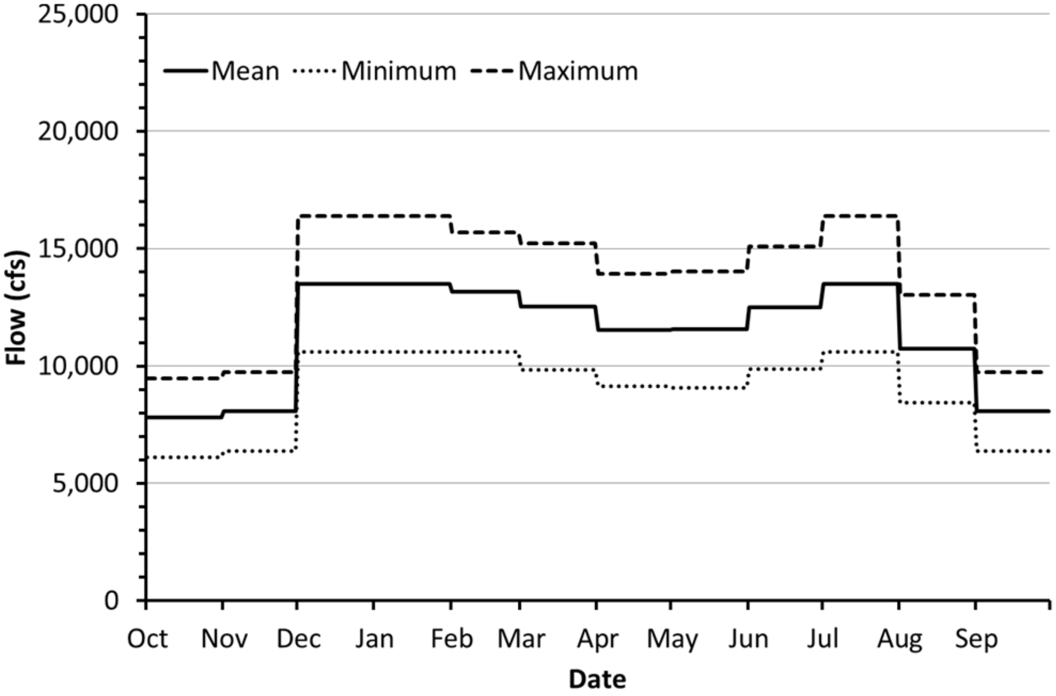


FIGURE 2-10 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-5

Reductions in August and September volumes also were intended to result in a slight increase in temperature relative to Alternative A at the confluence with the Little Colorado River. Warmer temperatures are expected to provide humpback chub and other native fish with some benefit during the critical time of year when many young-of-the-year (YOY) fish move from the Little Colorado River into the mainstem Colorado River.

Under base operations, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to monthly volume (7× monthly volume in kaf; e.g., daily range in a month with a volume of 800 kaf would be 5,600 cfs). The factor of 7 was chosen because it would provide improvement in sediment conservation relative to MLFF while limiting the effect on hydropower capacity and value. The down-ramp rate would be 2,500 cfs/hr (an increase from 1,500 cfs/hr under Alternative A); the up-ramp rate would be 4,000 cfs/hr as under Alternative A. Figure 2-10 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-11 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative C. Figure 2-12 shows details of hourly flows during a week in July.

2.2.3.2 Implementation Process for Experiments under Alternative C

Alternative C adopts a condition-dependent experimental approach. The underlying approach is to adopt a base operation that would serve as a long-term strategy to provide the conditions needed to support natural and cultural resources while reducing impacts on hydropower. Since there is uncertainty regarding future hydrologic conditions, sediment supply, and resource response to operational, experimental, and environmental conditions, Alternative C identifies condition-dependent flow and non-flow actions intended to safeguard against unforeseen adverse changes in resource impacts, and to prevent irreversible changes.

Alternative C would use decision trees, tied to information collected under a long-term monitoring program, that would be implemented annually or, in some cases, as needed, to determine operations and flow and non-flow actions in a given year. Implementation would be closely integrated with existing operational and experimental decision processes involving Reclamation, NPS, USGS, and GCDAMP. Decision trees for sediment-related and humpback chub–related actions are shown in Figures 2-13 and 2-14.

Implementation criteria for experimental elements of Alternative C are provided in Table 2-6. Included are the triggers for tests, conditions that would prevent a test from being conducted (implementation considerations), conditions that would cause the test to be terminated prior to completion (off-ramps), and the number of replicates needed. In general, two to three replicates are considered necessary for all tests. Only two tests may be needed if consistent results are obtained for each replicate (e.g., both tests showed a benefit, or both showed an adverse effect). Three tests may be needed if the first two tests showed opposite results (i.e., one benefit, one adverse effect).

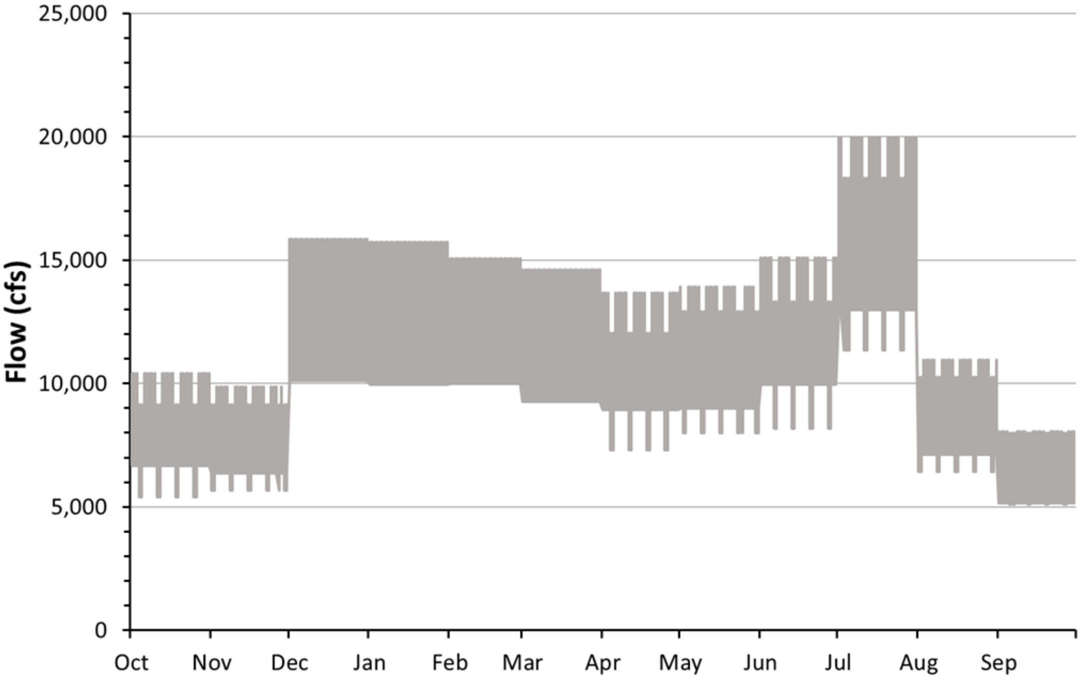


FIGURE 2-11 Simulated Hourly Flows under Alternative C in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-10. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

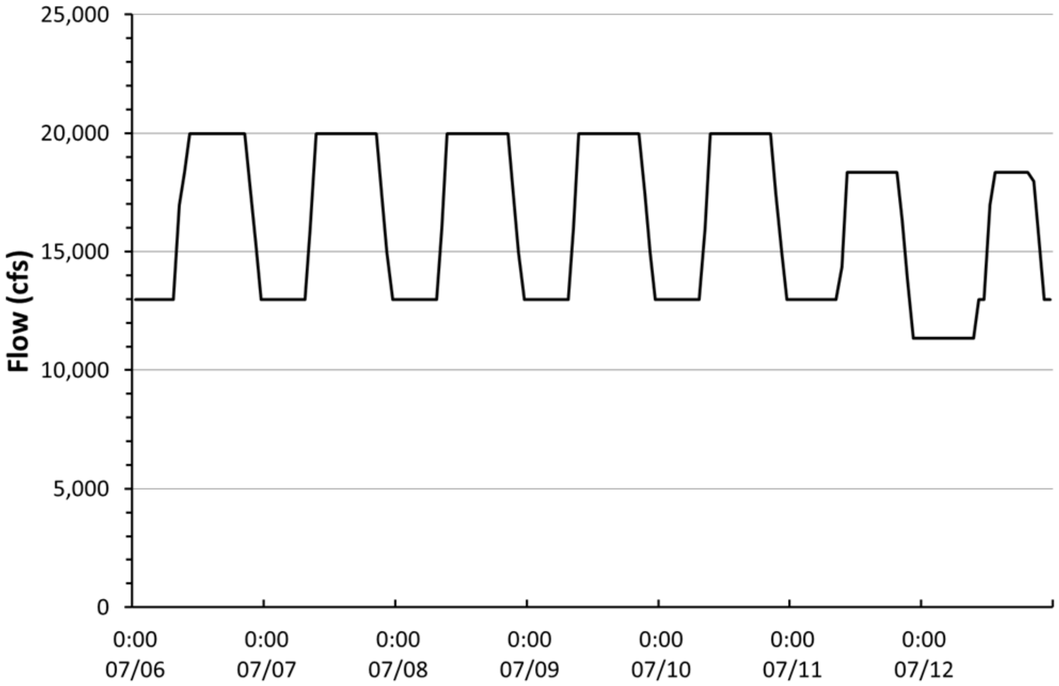
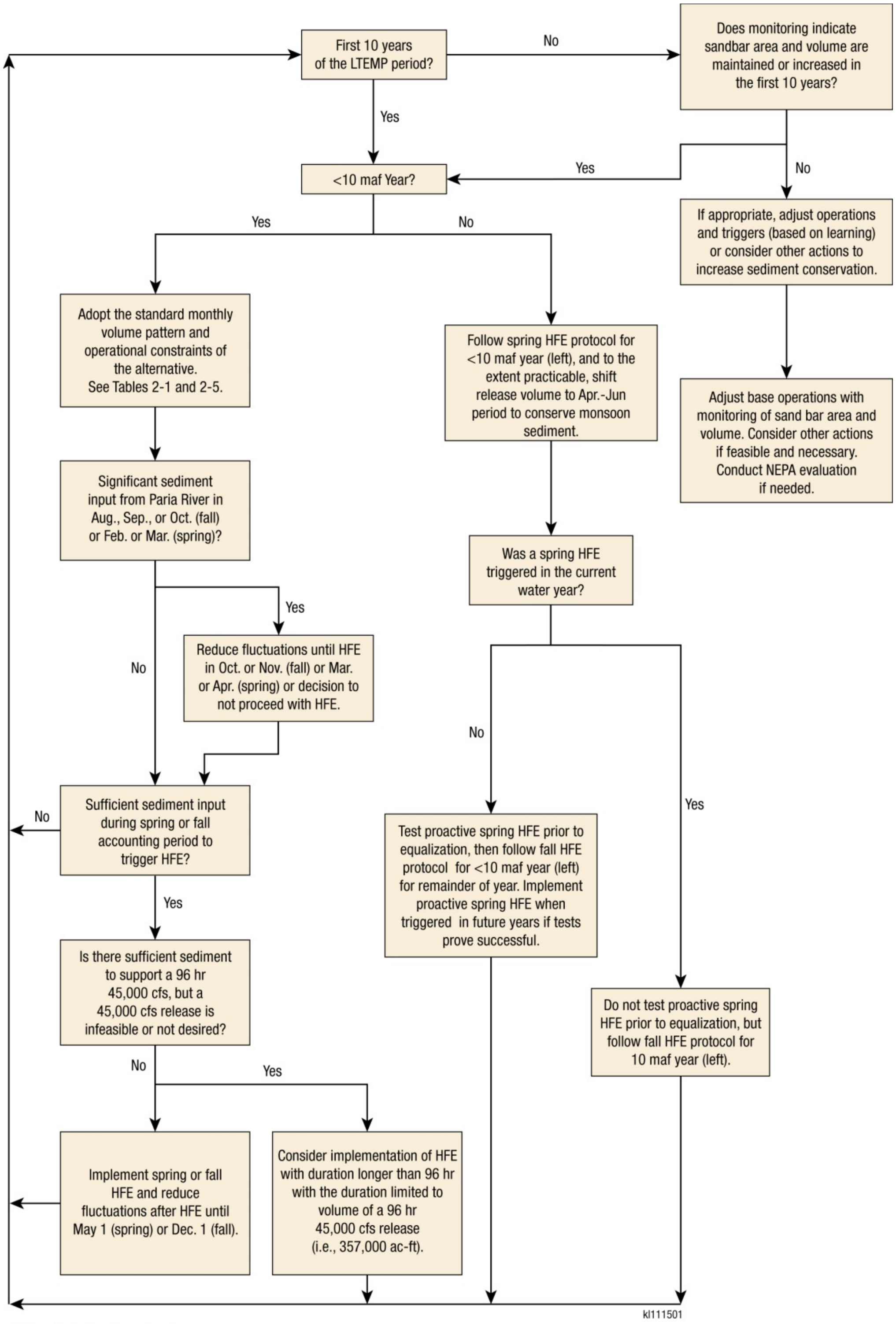
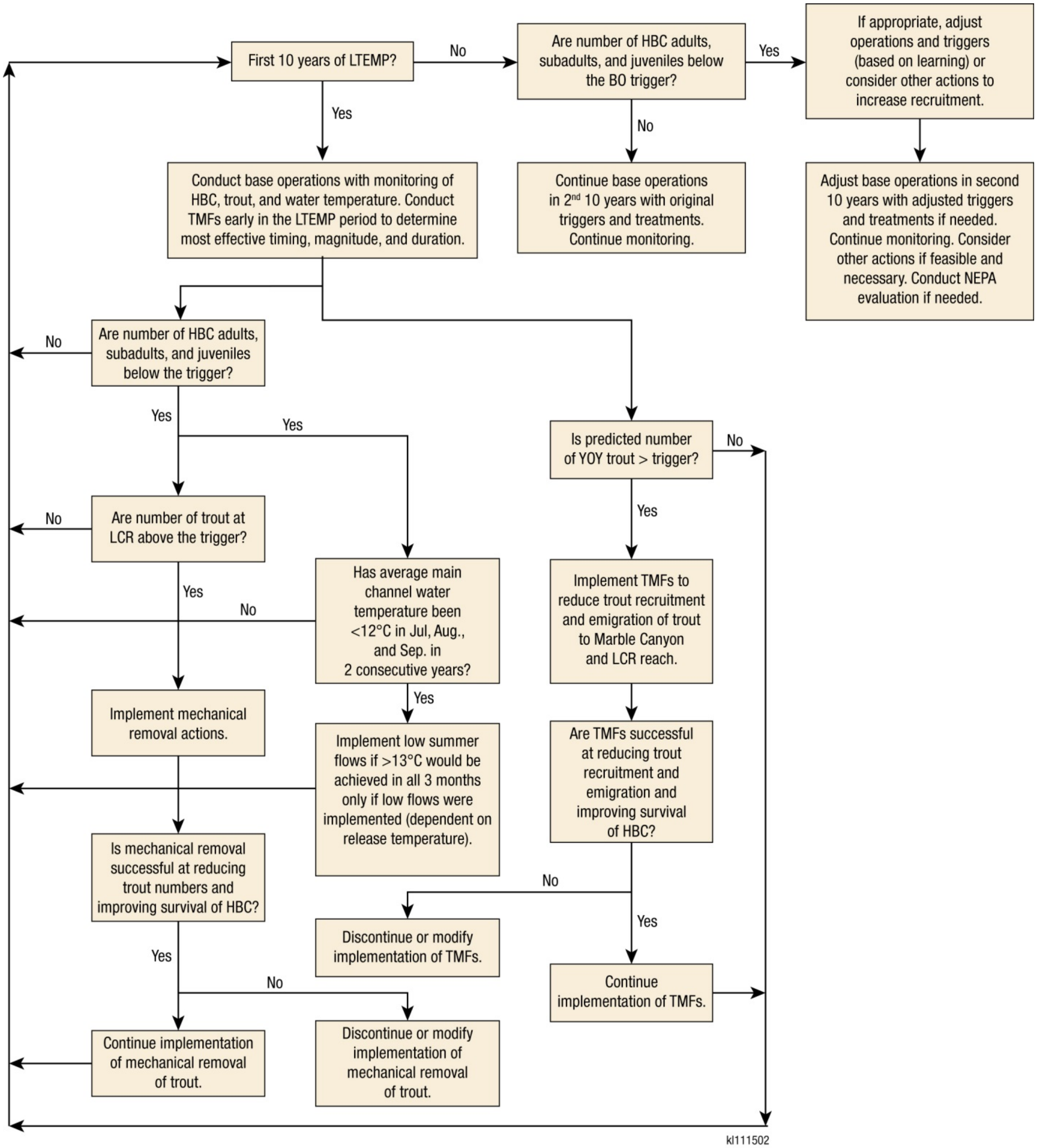


FIGURE 2-12 Simulated Hourly Flows under Alternative C for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)



HFE = High-Flow Experiment
NEPA = National Environmental Policy Act

FIGURE 2-13 Decision Tree for Sediment-Related Actions under Alternative C (Implementation would be conditional on considerations presented in Table 2-6. If off-ramp conditions listed in Table 2-6 exist, related experimental treatments would be discontinued.)



HBC = Humpback Chub
LCR = Little Colorado River
NEPA = National Environmental Policy Act
TCD = Temperature Control Device
TMF = Trout Management Flow

FIGURE 2-14 Decision Tree for Humpback Chub-Related Actions under Alternative C (Implementation would be conditional on considerations presented in Table 2-6. If off-ramp conditions listed in Table 2-6 exist, related experimental treatments would be discontinued.)

TABLE 2-6 Implementation Criteria for Experimental Treatments of Alternative C

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Sediment Experiments						
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources; unacceptable cumulative effects of sequential HFEs	HFEs were not effective in building sandbars; or adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when triggered and existing resource conditions allow
Proactive spring HFE up to 45,000 cfs (Apr., May, or Jun.)	Trigger: High-volume year with planned equalization releases (≥10 maf) Objective: Protect sand supply from balancing and equalization releases	Implement in each year triggered, dependent on resource condition and response	24 hr	Same as spring HFEs	Same as spring HFEs	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Sediment Experiments (Cont.)						
Fall HFE up to 45,000 cfs (Oct. or Nov.)	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources; unacceptable cumulative effects of sequential HFEs	Same as spring HFEs	Implement as adaptive treatment when triggered and existing resource conditions allow
Fall HFEs longer than 96-hr duration limited to the volume of a 96-hr 45,000-cfs release (357,000 ac-ft)	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of a 96-hr 45,000-cfs HFE, but a 45,000-cfs release is either not possible due to turbine outages or not desired Objective: Mobilize as much sediment as possible within the volume constraints of the HFE protocol	Implement in each year triggered	Limited by the volume of a 96-hr 45,000-cfs release (357,000 ac-ft) (a 137-hr 31,500-cfs release would comply with this volume constraint)	Same as fall HFEs	HFEs were not effective in building sandbars and resulting sandbars were no bigger than those created by shorter-duration HFEs; or adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Sediment Experiments (Cont.)						
Reduced fluctuations before and after HFEs (“load-following curtailment”)[d]	Trigger: Spring or fall HFE Objective: Retain sediment before HFE and reduce erosion of newly built sandbars after HFE	Implement when triggered	Up to 4 months before (Jul.–Nov.) and 2 months after (Oct. –Nov.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	Resulting sandbars were no bigger than those created without reduced fluctuation; or adverse impacts on trout fishery, humpback chub population, or other resources	Implement as adaptive treatment in association with HFEs when existing resource conditions allow
Aquatic Resource Experiments						
Trout management flows	Trigger: Predicted high trout recruitment in the Glen Canyon reach Objective: Test efficacy of flow regime on trout numbers and competition and predation of chub	Implement as needed when triggered; test may be conducted early in the 20-year period even if not triggered by high trout recruitment; contingent on Tribal consultation	Implemented in as many as 4 months (May–Aug.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	Little or no reduction in trout recruitment after at least three tests; or adverse impacts on trout fishery, humpback chub population, or other resources	Implement as adaptive treatment triggered by predicted high trout recruitment in Glen Canyon taking into consideration Tribal concerns

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Aquatic Resource Experiments (Cont.)						
Mechanical removal of trout in Little Colorado River reach	Trigger: Number of trout in Little Colorado River reach and number of humpback chub Objective: Test efficacy of control on trout numbers and competition and predation of chub	Implement in each year triggered unless determined ineffective, contingent on Tribal consultation	Up to six monthly removal trips (Feb.–Jul.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	Little or no reduction in trout density at the Little Colorado River, or unacceptable adverse impacts on humpback chub population or other resources	Implement as adaptive treatment when triggered taking into consideration Tribal concerns
Low summer flows (minimum daily mean 5,000 to 8,000 cfs) to target ≥13°C at Little Colorado River confluence	Trigger: Chub numbers are below trigger, water temperature has been <12°C for two consecutive years and target temperature of ≥13°C can only be achieved if drop to low flow Objective: Test efficacy of low summer flows on warming and humpback chub growth	If needed, two to three tests would be conducted in second 10 years of 20-year period; would not be implemented in first 10 years	3 months (Jul.– Sep.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	No increase in growth and recruitment of humpback chub; increase in warmwater nonnative species or trout at the Little Colorado River; or adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when conditions allow

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Riparian Vegetation Experiment						
Non-flow vegetation treatment activities	Trigger: None Objective: Improve vegetation conditions at key sites	Not applicable	20 years if successful pilot phase	Potential unacceptable site-specific impacts on sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, recreation, or other resources	Control and replanting techniques not effective or practical	Implement as adaptive treatment if invasive species can be reduced and native species increased

[a] Triggers will be modified as needed during the 20-year LTEMP period in an adaptive manner through processes including ESA consultation and based on the best available science utilizing the experimental framework for each alternative.

[b] Annual determination by the DOI. Any implementation would consider resource condition assessments and resource concerns using the annual process described in Section 2.2.3.3.

[c] Temporary or permanent suspension if the DOI determines effects cannot be mitigated.

[d] Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

In general, the first 10 years of base operations and strategic tests would be used to test the effects of operations and experimental elements on resources, to determine the strategy for the second 10 years of implementation, and, ultimately, to help determine a long-term strategy for Glen Canyon Dam operations and management actions that benefit important downstream resources, while minimizing impacts on hydropower to the extent practicable.

If sandbar area and volume are maintained or increased in the first 10 years of the LTEMP, the combination of base operations and HFE implementation would continue as prescribed above. If sandbar area and volume declines during the first 10 years of LTEMP, the HFE protocol and/or base operations may be modified, as allowable, to increase sediment conservation based on information learned in the first 10 years. In addition, the DOI would consider applicable planning processes for sediment augmentation and would conduct a separate NEPA evaluation of augmentation if it is considered feasible and necessary to prevent continued loss of sediment resources.

The relative effects of temperature and trout predation and/or competition on humpback chub recovery are uncertainties that affect the selection of a future management strategy; Alternative C would attempt to resolve this uncertainty. If after 10 years humpback chub are declining, nonstructural options for creating warmwater (i.e., flow manipulations) were not successful in providing warmer temperatures, and evidence suggests that trout control alone is not sufficient to improve humpback chub numbers, the DOI would consider a separate NEPA evaluation and other appropriate planning processes for a structural change such as a temperature control device (TCD). Research and monitoring during the first 10 years also could indicate that other factors (e.g., parasites, pathogens, warmwater nonnatives, or food base) are limiting humpback chub numbers. Such information would be used to develop additional condition-dependent actions or adjustments to base operations other than those included in the alternative at the start of the LTEMP.

No experimental flow actions are planned specifically for riparian vegetation under Alternative C. However, as described in the introduction to Section 2.2, a pilot experimental vegetation treatment program would be implemented under this and other alternatives to control nonnative vegetation encroachment and restore native vegetation at selected sites. If successful, vegetation treatment actions would be considered for inclusion as a regular non-flow action implemented throughout the LTEMP period. There are no specific experimental tests or condition-dependent actions that specifically focus on historic site preservation or Tribal cultural properties and resources other than operations and actions intended to reduce sediment transport in the active river channel. During the first 10 years of the LTEMP, continued evaluation of site stability and integrity would be undertaken in coordination with sediment evaluations consistent with the existing HFE protocol. Similarly, continued evaluation of Traditional Cultural Properties and resources of cultural concern would be evaluated by traditional practitioners and knowledgeable Tribal scholars. Mitigation would be undertaken to address resource impacts as determined necessary in consultation with Tribes. If monitoring indicates that historical properties preservation and Tribal cultural properties and resources are adversely affected by operations in the first 10 years of LTEMP implementation, the DOI would consider modification of operations to address aspects that, based on the results of monitoring and Tribal consultation, are causing degradation of these resources, and would consider an increase in non-flow actions, in consultation with the Tribes, to achieve these two resource goals.

Base operations under Alternative C would be experimentally modified in response to changes in resource conditions or the need for equalization as specified under the 2007 Interim Guidelines (Reclamation 2007a). The most important experiments relate to (1) implementation of HFEs in response to sediment inputs or equalization flows; (2) reductions in flow fluctuation in spring and fall in response to sediment inputs or the occurrence of HFEs; (3) flow actions in the spring and summer to control the Glen Canyon reach trout population; and (4) reductions in flows in certain years from July through September to provide warmer water for humpback chub near the confluence with the Little Colorado River. Non-flow actions are largely limited to those that are common to all alternatives as described at the beginning of Section 2.2.

2.2.3.3 Sediment-Related Experiments To Be Evaluated under Alternative C

Under Alternative C, the HFE protocol would be incorporated into the LTEMP process and extended to the end of the LTEMP period. Spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period using the same Paria River sediment input thresholds as used under the existing HFE protocol (Reclamation 2011b). HFE releases would be 1 to 96 hr long and between 31,500 cfs and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December 1 through June 30) or fall (July 1 through November 30) accounting periods, the maximum possible magnitude (not to exceed 45,000 cfs) and duration of HFE (up to approximately 140 hr) that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented (see Section 2.2.1 for a brief description of the existing HFE protocol).

Daily fluctuations for load-following would be reduced (except for instantaneous increases or decreases in flow to provide ancillary services)[3] after significant sediment input (sufficient input to trigger an HFE) from the Paria River in February or March (in anticipation of a spring HFE); or August, September, or October (in anticipation of a fall HFE) to increase the amount of sediment available for transport and deposition by spring and fall HFEs. These reduced fluctuations would occur until an HFE was implemented or a decision to not implement an HFE was made. If an HFE was implemented, the restriction in daily fluctuations would continue after the HFE occurred until May 1 (spring HFE) or December 1 (fall HFE) to reduce the erosion of newly formed sandbars. Under Alternative C, within-day fluctuations in hourly flows would be reduced to a within-day range of 2,000 cfs (i.e., ±1,000 cfs of the mean daily flow).

Sandbar monitoring after the 2011 equalization releases indicated that high rates of sandbar erosion and sediment transport occurred during equalization. To offset these high

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[3] Instantaneous changes in flows could occur within an hour to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

erosion and transport rates, Alternative C includes a proactive spring HFE in years when the April forecast indicates an annual release ≥10 maf. In these years, a 24-hr spring high flow (up to 45,000 cfs) would be tested prior to the occurrence of high equalization releases to determine the effectiveness of using high flows to conserve sediment downstream of the Paria River confluence above the elevation of equalization flows. The high flow would be timed to occur after the need for equalization has been determined, but before it was actually implemented. This would likely result in proactive spring HFEs occurring in May or June.

Under Alternative C, a proactive spring HFE would not be tested if there had been a spring HFE in the same water year. In high-volume years (≥10 maf) when there were no proactive spring HFEs, higher monthly volumes would be shifted to the April through June time period to the extent practicable to avoid sustained higher monthly flows and sediment transport rates at the end of the year.

The existing HFE protocol allows for HFEs up to 96 hr long, but there will be some years when a 45,000-cfs HFE is not feasible (e.g., one or more generating units are not available) and a longer duration release would be possible and desirable to achieve sediment goals. Under Alternative C, longer duration HFEs that did not exceed the total volume of a 96-hr, 45,000-cfs HFE (i.e., 357,000 ac-ft) would be allowed.

2.2.3.4 Aquatic Resource-Related Experiments To Be Evaluated under Alternative C

Under Alternative C, experimental flow and non-flow actions could be triggered by estimated numbers of rainbow trout, a combination of estimated numbers of rainbow trout and humpback chub, or measured water release temperature at Glen Canyon Dam, depending on the action under consideration. Humpback chub triggers and trout triggers would be developed with FWS, and there would be consultation with the AZGFD and other entities as appropriate. These triggers may be modified based on experimentation conducted early in the LTEMP period.

The humpback chub population in Grand Canyon has increased considerably under MLFF operations since the early 2000s. During this period, relatively warmer temperatures began to be reached at the Little Colorado River confluence as a consequence of lower reservoir elevations and concomitantly higher release temperatures; this warming may have contributed to the increase in humpback chub recruitment (Section 3.5.3). Base operations under Alternative C are intended to support continued and possibly improved humpback chub recruitment. Ongoing monitoring would be used to determine the need to adjust base operations to benefit humpback chub.

Under Alternative C, water temperature and trout numbers would be considered when determining the actions to take when chub numbers drop below the trigger levels identified above. Triggers for temperature and trout numbers would be used under Alternative C to trigger two potential actions: (1) low summer flows and (2) mechanical removal of trout. These are discussed individually below.

Two types of trout control actions are considered under Alternative C: (1) TMFs; and (2) mechanical removal. Both of these experimental actions could be implemented to reduce trout competition with and predation of humpback chub in the Little Colorado River reach or to manage the Glen Canyon rainbow trout fishery.

Mechanical Removal of Trout under Alternative C

Mechanical removal would occur at the Little Colorado River confluence (rainbow and brown trout) and would follow the protocol evaluated in the Nonnative Fish Control EA (Reclamation 2011a; see Section 2.2.1 of this EIS for a brief description of the protocol). Mechanical removal in the Little Colorado River reach (RM 56–RM 66) would be triggered by low humpback chub and high trout abundance estimates in the Little Colorado River reach. Mechanical removal, however, may be initiated in response to ongoing management of the trout fishery by the NPS (an element common to all alternatives) or in response to declining humpback chub numbers. The DOI recognizes that lethal mechanical removal is a concern for Tribes, particularly the Pueblo of Zuni, because it is a taking of life in the canyon. To the extent practicable, removal practices would include finding beneficial uses for removed fish, as has been practiced for trout removal actions at Bright Angel Creek.

Trout Management Flows under Alternative C

TMFs are a special type of fluctuating flow designed to reduce the recruitment of trout by disadvantaging YOY trout (Figure 2-15). TMFs have been proposed and developed on the basis of research described in Korman et al. (2005). The underlying premise of TMFs is based on observations that YOY trout tend to occupy near-shore shallow-water habitats to avoid predation by larger fish. TMFs feature repeated fluctuation cycles that consist of relatively high flows (e.g., 20,000 cfs) sustained for a period of time (potentially ranging from 2 days to 1 week) followed by a rapid drop to a very low flow (e.g., 5,000 cfs to 8,000 cfs).[4] This low flow would be maintained for a period of less than a day (e.g., 12 hr) to prevent adverse effects on the food base. Low flows would be timed to start in the morning, after sunrise, to expose stranded fish to direct sunlight and heat. Up-ramp rates to the TMF would be the same as the limit for this alternative overall (i.e., 4,000 cfs/hr). The down-ramp from peak to base would be over a single hour (e.g., 15,000 cfs/hr for a drop from 20,000 cfs to 5,000 cfs). In a TMF flow cycle, YOY trout are expected to occupy near-shore habitat when flows are highest, and would be stranded by the sudden drop to low flow. Because older age classes of trout tend to occupy deeper habitats toward the middle of the river channel, they are less susceptible to stranding and are less likely to be directly affected by TMFs. TMFs would be used to control trout recruitment in the Glen Canyon reach to manage the rainbow trout fishery, and to limit emigration of juvenile trout to downstream reaches, particularly to habitat occupied by humpback chub near the confluence

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[4] TMFs have the potential to result in stranding of boats in the Glen Canyon reach, as well as a potential risk to public safety. Public notification and outreach in advance of implementing TMFs, as is currently done for planned HFEs, would be necessary to avoid safety concerns.

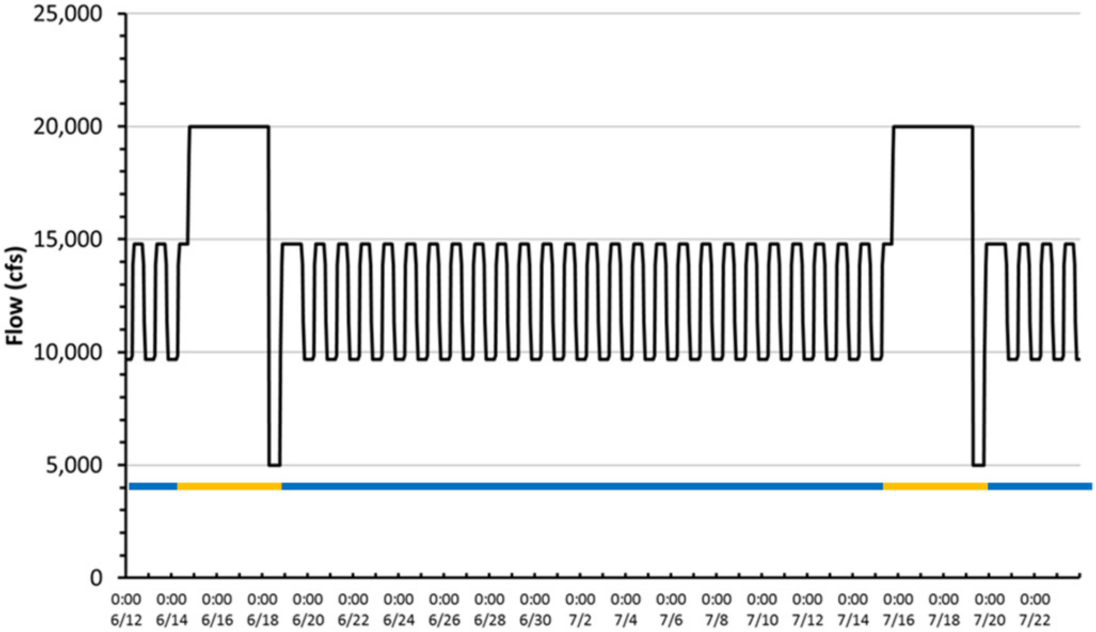

FIGURE 2-15 Example Implementation of a Two-Cycle TMF in June and July with Resumption of Normal Fluctuations between Cycles and Afterward (Monitoring for effectiveness would occur before and after each cycle. The horizontal line below the graph shows periods of normal fluctuation [blue] and TMFs [orange].)

with the Little Colorado River. Triggers for implementation of TMFs would be determined in consultation with the AZGFD.

It should be noted that several Tribes have expressed concerns about TMFs as a taking of life within the canyon without a beneficial use. The Pueblo of Zuni has expressed concern that the taking of life by trout stranding has an adverse effect on the Zuni value system. The joint-lead agencies will continue to work with the Tribes regarding options for trout management.

TMFs may be tested under this alternative early in the LTEMP period, even if not triggered by high trout recruitment. The intent of these early tests would be to determine the effectiveness of TMFs in reducing trout recruitment and the emigration of young trout to Marble Canyon and the Little Colorado River reach. The condition of the trout fishery, as determined in consultation with AZGFD, and potential impacts on other important resources would be considered prior to implementing TMFs. If TMFs are determined to be effective for these goals while minimizing impacts on other resources, they may be deployed on a regular or triggered basis. TMFs would be tested two to three times in the early part of the LTEMP period while attempting to minimize confounding effects with other experimental treatments. Tests would start with a conservative application of two cycles in June and July (Figure 2-15), but could be increased based on experimental testing to as many as three cycles per month for 3 months (May, June, and July).

Low Summer Flows under Alternative C

If water temperatures at the Little Colorado River confluence have been relatively cold (i.e., do not exceed 12°C, the minimum temperature for humpback chub growth) in two consecutive years,[5] low summer flows (no lower than a mean daily flow of 5,000 cfs) would be provided if the water released from the dam is sufficiently warm to result in at least 13°C at the confluence in the months of July, August, and September. A target temperature of 13°C was chosen because it represents an improvement over the minimum temperature needed for growth, 12°C. Note that reduction in summer flows would necessitate increasing flows in other months relative to base operations (Table 2-7; Figure 2-16).

The ability to achieve target temperatures at the Little Colorado River confluence by providing lower flows is dependent on release temperatures, which are in turn dependent on reservoir elevation. For example, using the temperature model of Wright, Anderson et al. (2008), in an 8.23-maf year, release temperatures of 9.6°C, 9.8°C, and 10.5°C would be needed in July, August, and September, respectively, to achieve a target temperature of 13°C at the Little Colorado River confluence at flows of 8,000 cfs.

Release temperatures fall into three categories for any temperature target: (1) too low to warm to target temperature even at low flow; (2) high enough to warm to target temperature only if low flows (5,000 cfs to 8,000 cfs) are provided; and (3) high enough to achieve target temperature regardless of the flow level. Low flows would only be triggered in years that fell into the second category. This is a fairly rare situation; modeling of 63 20-year periods determined that low summer flows would be triggered in at most four years per 20-year period.

A decision to conduct low summer flows in a year would be made by May 1. Such a decision would be based on reservoir and temperature modeling and other resource conditions, in addition to annual water delivery requirements. Because fluctuations have relatively little effect on mainstem water temperature and humpback chub, minor within-day flow fluctuations (i.e., ±1,000 cfs) would be allowed. If triggered, low summer flows would be provided in at least 2 years (not necessarily consecutive), and the response of chub would be determined.

2.2.4 Alternative D (Preferred Alternative)

The objective of Alternative D (the preferred alternative) is to adaptively operate Glen Canyon Dam to best meet the resource goals of the LTEMP (Section 1.4). Like Alternative C, Alternative D features condition-dependent flow and non-flow actions that would be triggered by resource conditions.

Alternative D was developed by the DOI after a full analysis of the other six LTEMP alternatives had been completed. This alternative was identified as the preferred alternative by

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[5] This temperature trigger is the same as that identified by FWS in the Nonnative Fish Control BO (FWS 2011c).

TABLE 2-7 Flow Parameters for a Year with Low Summer Flows under Alternative C in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	480	0.0583	7,806	3,360
November	480	0.0583	8,067	3,360
December	830	0.1009	13,499	5,810
January	830	0.1009	13,499	5,810
February	730	0.0887	13,148	5,111
March	771	0.0937	12,539	5,397
April	849	0.1032	14,273	5,945
May	880	0.1069	14,306	6,157
June	920	0.1118	15,462	6,440
July	492	0.0598	8,000	2,000
August	492	0.0598	8,000	2,000
September	476	0.0578	8,000	2,000

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts or other factors, and based on application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

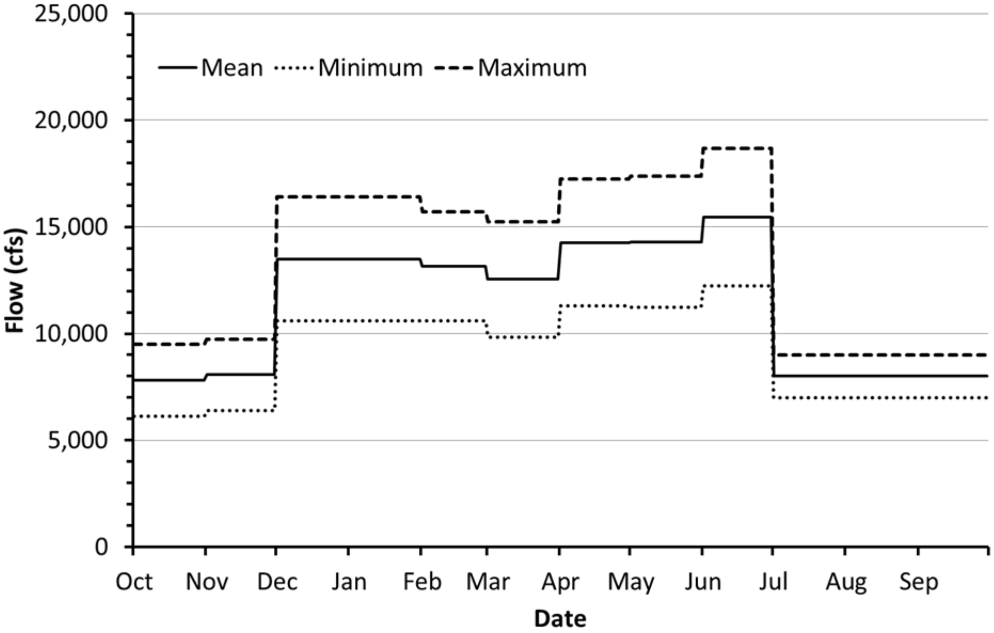


FIGURE 2-16 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-6

the DOI, and its identification as the preferred alternative was supported by WAPA and the Basin States. Alternative D was also considered the environmentally preferred alternative, based on its relative impacts (compared to other alternatives) on the full range of environmental resources. Alternative D adopts operational and experimental characteristics from Alternative C and Alternative E. The effects of operations under Alternatives C and E were modeled, and the results of that modeling suggested ways in which characteristics of each could be combined and modified to improve performance and reduce impacts, while meeting the purpose, need, and objectives of the LTEMP EIS. Alternative D is expected to result in an improvement in conditions for humpback chub, trout, and the aquatic food base; have the least impact on vegetation, wetlands, and terrestrial wildlife; improve sandbar building potential and conserve sediment; sustain or improve conditions for reservoir and river recreation; improve preservation of cultural resources; respect and enhance Tribal resources and values; and have limited impacts on hydropower resources.

On the basis of modeling results for Alternative C and E, discussions with subject matter experts and Cooperating Agencies, and specific impact analyses of various potential Alternative D characteristics conducted using the screening tool (see Section 2.1 for a discussion of the models integrated in the screening tool), the DOI developed the operational and experimental characteristics of Alternative D. This formulation of the alternative then was modeled with the same models used for the analysis of the original six alternatives.

Adjustments were made to Alternative D after the integrated multiple-resource modeling, illustrated in Figure 4-1, was completed in March 2015, prior to the release of the DEIS in January 2016. This modeling considered a full-range of hydrology and sediment conditions, as described in Section 4.1. Adjustments to Alternative D included (1) an increase in release volume in August with corresponding decreases in May and June (in an 8.23-maf year, the increase was 50 kaf in August, i.e., from 750 to 800 kaf; and a reduction of 25 kaf each in May and June; these changes were applied proportionally to monthly volumes in drier and wetter years); (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE; and (4) a prohibition on sediment-triggered spring HFEs in the same water year as an extended-duration (>96 hr) fall HFE. Adjustments made to Alternative D after the DEIS was published, and based on comments received from Cooperating Agencies and stakeholders on the DEIS, included (1) elimination of load-following curtailment after a fall HFE and (2) a prohibition on proactive spring HFEs in the same water year as an extended-duration fall HFE.

The description of Alternative D provided in this section represents the final version of the alternative that resulted from these changes.

Once the adjustments to Alternative D were made, analyzing them using multiple-resource modeling would have taken many months and incurred significant additional cost. Therefore, instead of performing multiple-resource modeling on the effects of these adjustments, the joint-leads chose to perform streamlined modeling using the screening tool (see Section 2.1 for a description of this modeling tool) and analysis to assess the magnitude and direction of these effects of the adjustments. As described in Section 4.1, for most resources, these adjustments to Alternative D are expected to result in little if any change in impacts relative to those predicted for the earlier modeled version of Alternative D. However, the streamlined analysis did show that the adjustments would result in some changes to the expected impacts on sediment and hydropower resources, but that for all resources other than hydropower these changes would not affect the relative performance of Alternative D compared to other alternatives (see discussion in Section 4.1). Because the adjustments to Alternative D would not change Alternative D's relative performance for most resources, and the changes to hydropower impacts would be reductions—not increases—in impact, the agencies chose not to perform additional multiple-resource modeling. In addition to presenting the original multiple-resource modeling results, the results of the streamlined modeling evaluating the effects of these adjustments on sediment and hydropower are presented in Sections 4.3.3.4 and 4.13.3.4, respectively. Because, for most resources, these adjustments are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D, the only quantitative analysis results presented in those sections of the EIS are those from the original multiple-resource modeling.

Operational characteristics of Alternative D are presented in Table 2-1, and condition-dependent experimental elements are summarized in Table 2-2. The alternative uses decision trees to identify when a change in the implementation of experimental actions may be considered; however, DOI will retain sufficient flexibility in the implementation of experiments to ensure the protection of resources (Section 2.2.4.3). Experimental flows and non-flow actions could be triggered by changes in sediment input, humpback chub numbers and population structure, trout numbers, and water temperature after consideration of effects on all resources. Alternative D differs from Alternatives C and E in the specific trigger conditions and actions that would be taken.

2.2.4.1 Base Operations under Alternative D

Under Alternative D, the pattern of monthly releases would be relatively even compared to under Alternative A. The total monthly release volume of October, November, and December would be equal to that under Alternative A (i.e., 2 maf in years with ≥ 8.23 maf annual release volume) to avoid the possibility of the operational tier differing from that of Alternative A, as established in the Interim Guidelines (Reclamation 2007a). The August volume was set to a moderate volume level (800 kaf in an 8.23-maf release year) to consider both sediment conservation prior to a potential HFE and power-production and capacity concerns. January through July monthly volumes were set at levels that roughly track WAPA's contract rate of delivery (CROD). This produced a redistribution of monthly release volumes under Alternative D that would result in the most even distribution of flows of any alternative except for Alternative G.

Under base operations of Alternative D, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to the volume of water scheduled to be released during the month (10 × monthly volume in kaf in the high-demand months of June, July, and August and 9 × monthly volume in kaf in other months; Table 2-8; Figure 2-17). For example, the daily fluctuation range in July with a scheduled release volume of 800 kaf would be 8,000 cfs, and the daily fluctuation range in December with the same scheduled release volume would be 7,200 cfs.

TABLE 2-8 Flow Parameters under Alternative D in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	5,783
November	642	0.0780	10,781	5,774
December	716	0.0870	11,643	6,443
January	763	0.0927	12,409	6,867
February	675	0.0820	12,154	6,075
March	713	0.0866	11,596	6,417
April	635	0.0772	10,672	5,715
May	632	0.0768	10,278	5,688
June	663	0.0806	11,142	6,630
July	749	0.0910	12,181	7,490
August	800	0.0972	13,011	8,000
September	600	0.0729	10,083	5,400

[a] Within a year, monthly operations may be increased or decreased based on factors referenced in Section 2.2.4.2.

[b] Values have been rounded.

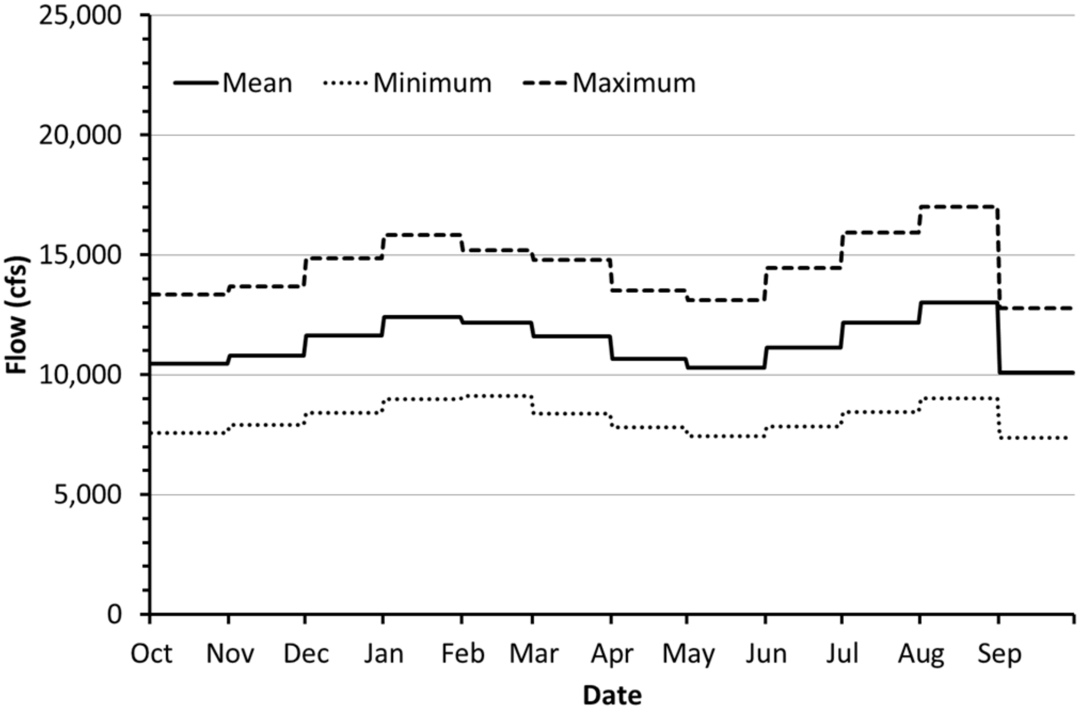


FIGURE 2-17 Mean, Minimum, and Maximum Daily Flows under Alternative D in an 8.23-maf Year Based on Values Presented in Table 2-8

The maximum allowable daily fluctuation range in flows in any month would be 8,000 cfs, which is also the maximum daily fluctuation range under Alternative A.

An 8,000-cfs maximum daily fluctuation limit was established in the 1996 ROD (Reclamation 2006) to address safety, recreation, and sediment concerns (Reclamation 1995). The analysis conducted for the LTEMP EIS has not identified new evidence to suggest that these concerns are no longer relevant or that this fluctuation limit is no longer appropriate. The determination of 8,000 cfs as a maximum daily fluctuation level that is suitable for recreation was based on Bishop et al. (1995). Bishop et al. surveyed both the river guides and the general public regarding preferences, and the river guides reported a preference for a maximum of 8,000 cfs daily change for a "tolerable recreation experience" under relatively high average daily flows. The current river guide community has continued to state the preference for retaining the 8,000-cfs maximum daily fluctuation that is currently in place.

The down-ramp rate under Alternative D would be limited to no greater than 2,500 cfs/hr, which is 1,000 cfs/hr greater than what is allowed under Alternative A. The up-ramp rate would be 4,000 cfs/hr, and this is the same as what is allowed under Alternative A.

Figure 2-17 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-18 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative D. Figure 2-19 shows details of hourly flows during a week in July.

Annually, Reclamation will develop a hydrograph based on the characteristics above. Reclamation will seek consensus on the annual hydrograph through monthly operational coordination calls with governmental entities, and regular meetings of the GCDAMP Technical Working Group (TWG) and AMWG. Reclamation will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, and BIA), WAPA, and representatives from the Basin States and UCRC. The purpose of these meetings or calls is for the participants to share and seek information on Glen Canyon Dam operations. One liaison from each Basin State and from the UCRC may participate in the monthly operational coordination meetings or calls.

2.2.4.2 Operational Flexibility under Alternative D

Reclamation retains the authority to utilize operational flexibility at Glen Canyon Dam because hydrologic conditions of the Colorado River Basin (or the operational conditions of Colorado River reservoirs) cannot be completely known in advance. Consistent with current operations, Reclamation, in consultation with WAPA, will make specific adjustments to daily and monthly release volumes during the water year. Monthly release volumes may be rounded for practical implementation or for maintenance needs. In addition, when releases are actually implemented, minor variations may occur regularly for a number of operational reasons that cannot be projected in advance.

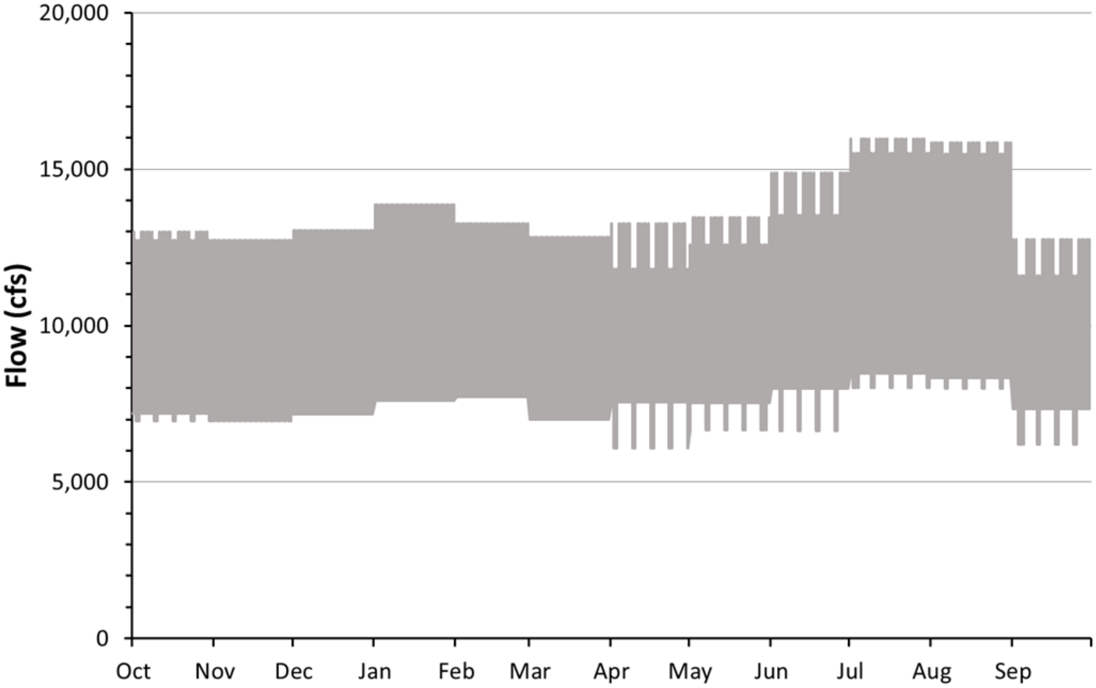


FIGURE 2-18 Simulated Hourly Flows under Alternative D in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-17. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

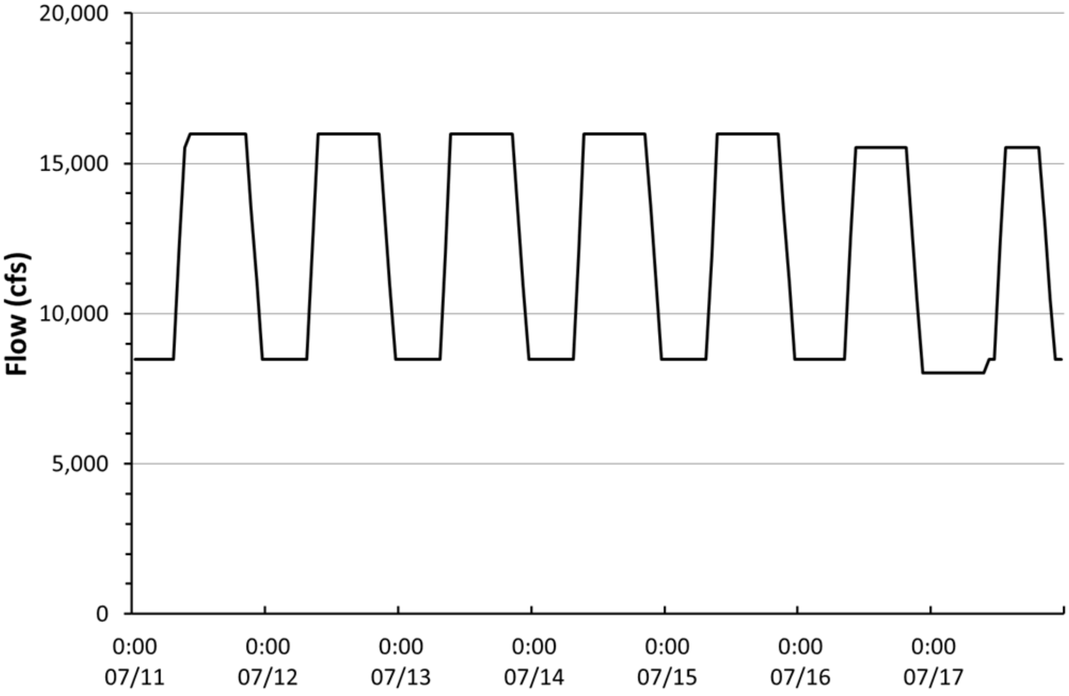


FIGURE 2-19 Simulated Hourly Flows under Alternative D for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

Reclamation also will make specific adjustments to daily and monthly release volumes, in consultation with other entities as appropriate, for a number of reasons, including operational, resource-related, and hydropower-related issues. Examples of these adjustments may include, but are not limited to, the following:

- For water distribution purposes, volumes may be adjusted to allocate water between the Upper and Lower Basins consistent with the Law of the River as a result of changing hydrology;
- For resource-related issues that may occur uniquely in a given year, release adjustments may be made to accommodate nonnative species removal, to assist with aerial photography, or to accommodate other resource considerations separate from experimental treatments under the LTEMP;
- For hydropower-related issues, adjustments may occur to address issues such as electrical grid reliability, actual or forecasted prices for purchased power, transmission outages, and experimental releases from other Colorado River Storage Project dams.

In addition, Reclamation may make modifications under circumstances that may include operations that are prudent or necessary for the safety of dams, public health and safety, other emergency situations, or other unanticipated or unforeseen activities arising from actual operating experience (including, in coordination with the Basin States, actions to respond to low reservoir conditions as a result of drought in the Colorado River Basin). In addition, the Emergency Exception Criteria established for Glen Canyon Dam will continue under this alternative. (See, e.g., Section 3 of the Glen Canyon Operating Criteria at 62 FR 9448, March 3, 1997.)

Section 2.2.4.3 addresses adjustments to base operations for adaptive management-based experimental operations with flow components.

2.2.4.3 Implementation Process for Experiments under Alternative D

Alternative D identifies condition-dependent flow and non-flow treatments intended to safeguard against unforeseen adverse changes in resource impacts, and to prevent irreversible changes to those resources. These condition-dependent treatments would be implemented experimentally during the LTEMP period unless they prove ineffective or result in unacceptable adverse impacts on other resources.

Prior to implementation of any experiment, the relative effects of the experiment on the following resource areas will be evaluated and considered: (1) water quality and water delivery, (2) humpback chub, (3) sediment, (4) riparian ecosystems, (5) historic properties and traditional cultural properties, (6) Tribal concerns, (7) hydropower production and WAPA's assessment of the status of the Basin Fund, (8) the rainbow trout fishery, (9) recreation, and (10) other resources. Although these key resources are listed for consideration on a regular basis, DOI intends to retain sufficient flexibility in implementation of experiments to allow for response to unforeseen circumstances or events that involve any other resources not listed here. The recent discovery of nonnative green sunfish in the Glen Canyon reach illustrates the need to be responsive to unforeseen conditions. DOI will engage in the communication and consultation process described in Section 2.2.4.4, when making decisions regarding implementation of experiments.

The proposed approach differs fundamentally from a more formal experimental design (e.g., before-after control-impact design, factorial design) that attempts to resolve uncertainties by controlling for or treating potentially influential or confounding factors. There are several reasons to avoid such a formal design and instead focus on the condition-dependent approach described here. Among these are (1) the difficulties in controlling for specific conditions in a system as complex as the Colorado River; (2) wide variability in temperature and flow conditions that are important drivers in ecological processes; (3) inherent risk of some experimentation to protected sensitive resources, in particular, endangered humpback chub; (4) conflicting multiple-use values and objectives; and (5) low expected value-of-information for the uncertainties that could be articulated, and around which a formal experimental design would be established. For these reasons, a condition-dependent adaptive approach is proposed.

The alternative utilizes the principle that a condition-dependent adaptive design is preferable to a formal experimental design because of the need for a flexible and adaptive program that is responsive to learning. A more formal experimental design, while potentially beneficial in resolving specific uncertainties, would involve multiple-year tests under different conditions, and with sufficient replicates of experimental conditions to statistically test the significance of treatment effects. Such an experimental design would necessarily span a period of years, during which environmental conditions would undoubtedly vary, and thus confound interpretation of results. The duration of the experiment could be lengthened and the potential for confounding effects increased if there was a desire to test system response under specific conditions that cannot be controlled (e.g., annual volume, water temperature, sediment load, and species population levels). These factors make a formal experimental design impractical in the Grand Canyon. Like Alternatives C and E, Alternative D would use condition-dependent triggers to inform operations and experimental flow and non-flow treatments in a given year.

Implementation criteria for condition-dependent experimental treatments of Alternative D are provided in Table 2-9, and decision trees for implementation of experimental treatments are presented in Figures 2-20 and 2-21. (Note: In both of these figures, triggering would also be conditional on annual implementation considerations and long-term off-ramps presented in Table 2-9. The nodes shown in rectangles are condition-dependent action nodes; the nodes shown in circles are information-dependent nodes that require the evaluation of accumulated evidence.) Included in Table 2-9 are the triggers for experimental changes in operations, implementation considerations for determining if an experimental treatment should proceed, conditions that would cause the treatment to be terminated prior to completion (i.e., off-ramps), and the number of replicates that are initially considered needed. In many cases, two to three replicates of an experimental treatment are considered necessary. The results of these tests would be used to determine if these condition-dependent treatments should be retained as part of the suite of long-term actions implemented under LTEMP. In other cases, following the process

TABLE 2-9 Implementation Criteria for Experimental Treatments of Alternative D

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
***Sediment Treatments*[d]**						
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Not conducted during first 2 years of LTEMP, otherwise implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs; sediment-triggered spring HFEs will not occur in the same water year as an extended-duration (>96 hr) fall HFE	Sediment-triggered spring HFEs are not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Proactive spring HFE up to 45,000 cfs (Apr., May, or Jun.)	Trigger: High-volume year with planned equalization releases (≥10 maf) Objective: Protect sand supply from equalization releases	Not conducted during first 2 years of LTEMP, otherwise implement in each year triggered, dependent on resource condition and response	First test 24 hr; subsequent tests could be shorter, but not longer, depending on results of first tests	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs; would not be implemented in the same water year as a sediment-triggered spring HFE or extended-duration fall HFE	Proactive spring HFEs are not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Sediment Treatments (Cont.)						
Fall HFE ≤96 hr up to 45,000 cfs in Oct. or Nov.	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs	This type of fall HFE is not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Fall HFEs longer than 96-hr duration up to 45,000 cfs in Oct. or Nov.	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE longer than a 96-hr, up to 45,000-cfs flow Objective: Rebuild sandbars	Implement in each year triggered; limited to total of four tests in LTEMP period	Up to 250 hr depending on availability of sand duration of first test not to exceed 192 hr	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs	Extended-duration fall HFEs are not effective in building sandbars; resulting sandbars are no bigger than those created by shorter-duration HFEs; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
***Aquatic Resource Treatments*[e]**						
Trout management flows	Trigger: Predicted high trout recruitment in the Glen Canyon reach Objective: Test efficacy of flow regime on trout numbers and survival of humpback chub	Implement as needed when triggered after consultation with Tribes; test may be conducted early in the 20-year period even if not triggered by high trout recruitment[f]	Implemented in as many as 4 months (May–Aug.)	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	TMFs have little or no effect on trout recruitment after at least three tests; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment triggered by predicted high trout recruitment in Glen Canyon, taking into consideration Tribal concerns
Tier 1: Expanded translocation of humpback chub in the Little Colorado River	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective	As needed	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Expanded translocation has little or no effect on increasing the number of adult or subadult humpback chub; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Tier 1: Implement head-start program for larval humpback chub	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective	As needed	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Head-start program has little or no effect on increasing the number of adult or subadult humpback chub; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Aquatic Resource Treatments (Cont.)						
Tier 2: Mechanical removal of nonnative fish in Little Colorado River reach	Trigger: Tier 1 actions ineffective; humpback chub numbers in Little Colorado River below Tier 2 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective after consultation with Tribes	Monthly removal trips (Feb.–Jul.) until "predator index" or adult humpback chub reach acceptable levels (see Appendix O)	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Mechanical removal has little or no effect on reducing predator index in the Little Colorado River reach; no population-level benefit on humpback chub; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered, taking into consideration Tribal concerns
Low summer flows (minimum daily mean 5,000 to 8,000 cfs) to target ≥ 14°C at Little Colorado River confluence	Trigger: Initial experiment: in the second 10 years of the LTEMP period, when target temperature of ≥14°C can be achieved only with low summer flow Objective: Increase humpback chub growth	Subsequent experimental use if: (1) initial test was successful, (2) humpback chub population concerns warrant their use, (3) water temperature appears to be limiting recruitment, and (4) target temperature of ≥14°C could be achieved only with low summer flow	3 months (Jul.–Sep.)	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Low summer flows do not increase growth and recruitment of humpback chub; increase in warmwater nonnative species or trout at the Little Colorado River; long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed; or sufficient warming does not occur as predicted	Implement as adaptive treatment when conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Aquatic Resource Treatments (Cont.)						
Macroinvertebrate production flows	Trigger: None Objective: Improve food base productivity and abundance or diversity of mayflies, stoneflies, and caddisflies	Target two to three replicates	Up to 4 months (May–Aug.)[g]	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; coordinate planning with other experiments to avoid confounding conditions or results	Steady weekend flows have little or no benefit on food base, trout fishery, or native fish; increase in warmwater nonnative species or trout at the Little Colorado River; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment in target months when conditions allow
Riparian Vegetation Treatments						
Non-flow vegetation treatments	Trigger: None Objective: Improve vegetation conditions at key sites	Not applicable	20 years if successful pilot phase	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Control and replanting techniques are not effective or practical; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment if invasive species can be reduced and native species increased

[a] Triggers will be modified as needed during the 20-year LTEMP period in an adaptive manner through processes including ESA consultation and based on the best available science utilizing the experimental framework for each alternative.

[b] Annual determination by the DOI. Any implementation would consider resource condition assessments and resource concerns using the annual processes described in Sections 2.2.4.3 and 2.2.4.4.

[c] Suspension of experiment if the DOI determines effects cannot be mitigated.

[d] Details of implementation of sediment experiments are presented in Section 2.2.4.5.

[e] Details of implementation of aquatic resource experiments are presented in Section 2.2.4.6.

[f] The decision to conduct TMFs in a given year would consider the resource conditions, as specified in Section 2.2.4.3, and would also involve considerations regarding the efficacy of the test based on those resource conditions.

[g] The duration and other characteristics of experimental macroinvertebrate production flows could be adjusted based on the results of initial experiments.

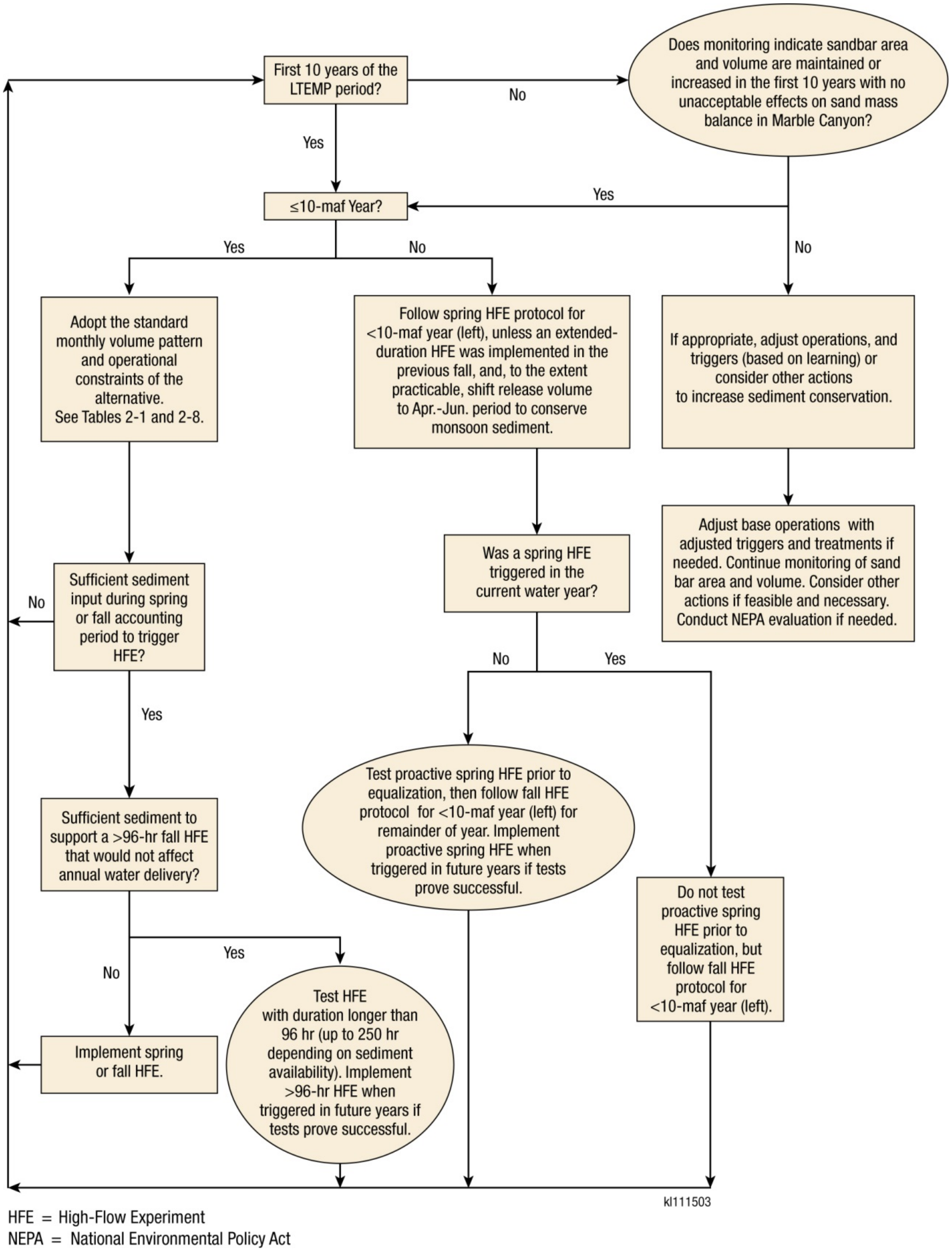
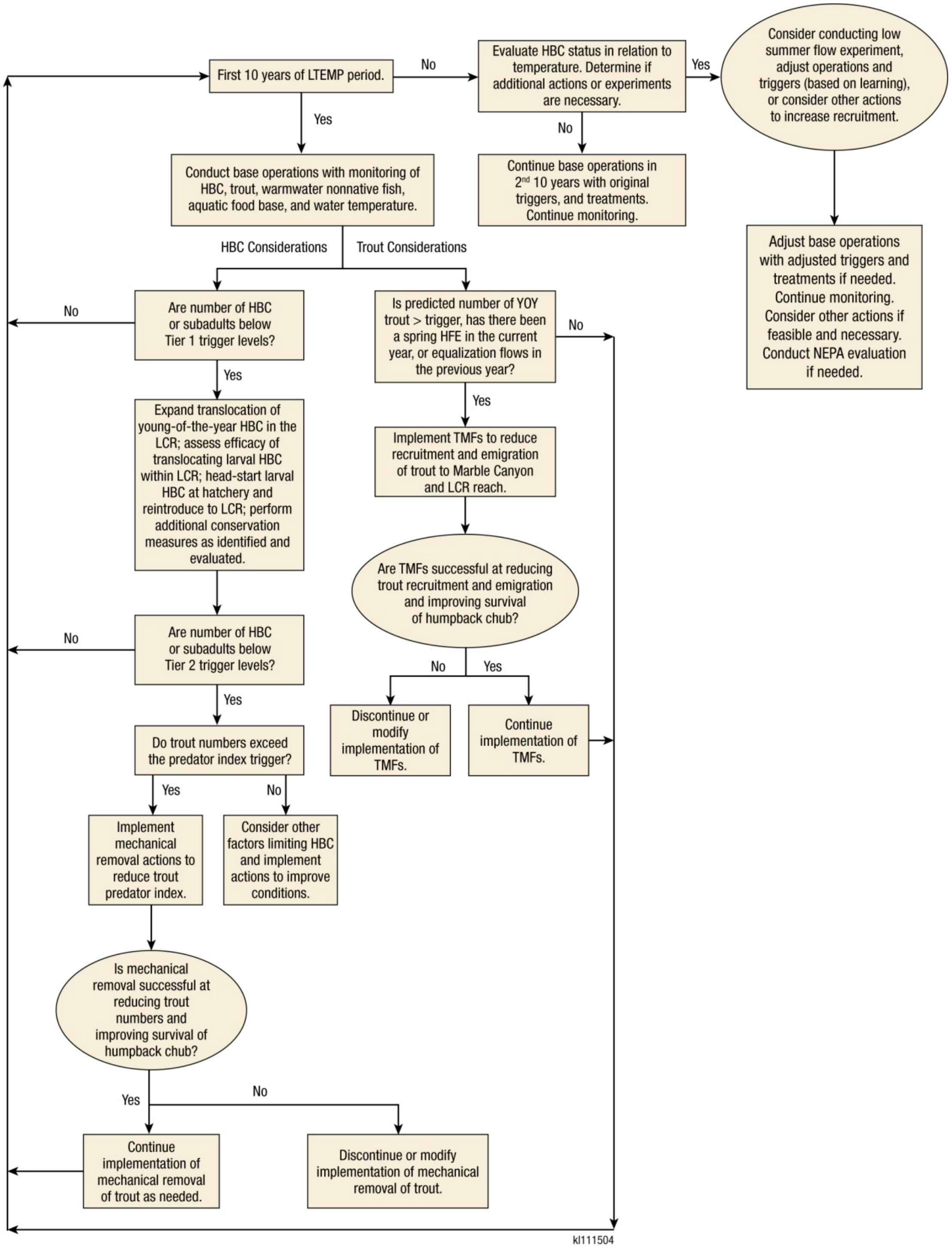


FIGURE 2-20 Decision Tree for Implementation of Sediment-Related Experimental Treatments under Alternative D (Implementation would be conditional on annual considerations presented in Section 2.2.4.3. If off-ramp conditions listed in Table 2-9 exist, related experimental treatments would be suspended.)



HBC = Humpback Chub
HFE = High-Flow Experiment
LCR = Little Colorado River
NEPA = National Environmental Policy Act
TMF = Trout Management Flow

FIGURE 2-21 Decision Tree for Implementation of Aquatic Resource-Related Experimental Treatments under Alternative D (Implementation would be conditional on annual considerations presented in Section 2.2.4.3. If off-ramp conditions listed in Table 2-9 exist, related experimental treatments would be suspended.)

described elsewhere in this section, implementation of experimental treatments would continue throughout the LTEMP period if triggered (e.g., spring and fall HFEs), except in years when it was determined that the proposed experiment could result in unacceptable adverse impacts on resource conditions. For these experiments, effectiveness would be monitored and the experiments would be terminated or modified, only if sufficient evidence suggested the treatment was ineffective or had unacceptable adverse impacts on other resources. All experimental treatments would be closely monitored for adverse side effects on important resources. At a minimum, an unacceptable adverse impact would include significant negative impacts on resources as a result of experimental treatments that have not been analyzed for Alternative D in the LTEMP EIS.

Sections 2.2.4.5 and 2.2.4.6 describe specific processes for the development and implementation of experiments related to sediment, aquatic resources, and riparian vegetation. The overall approach attempts to strike a balance between identifying specific experiments and providing flexibility to implement those experiments when resource conditions are appropriate. As discussed above, rather than proposing a prescriptive approach to experimentation, an adaptive management-based approach that is responsive and flexible would be used to adapt to changing environmental and resource conditions and new information. The potential for confounding interactions among individual experimental treatments is discussed when relevant for each of the proposed treatments. Given the size of the project area and the variability inherent in the system, this pragmatic approach to experimentation is warranted. Although confounding treatments are possible given the complexity of the experimental plan, they are not expected to limit learning over the life of the LTEMP.

2.2.4.4 Communication and Consultation Process for Alternative D

In implementing the processes described in Section 2.2.4.3 and the associated decision process shown in Figures 2-20 and 2-21, the DOI will exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources. As an initial platform to discuss potential future experimental actions, the DOI will hold GCDAMP annual reporting meetings for all interested stakeholders; these meetings will present the best available scientific information and learning from previously implemented experiments and ongoing monitoring of resources. As a follow-up to this process, the DOI will meet with the TWG to discuss the experimental actions being contemplated for the year.

The DOI also will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA, and Reclamation), WAPA, AZGFD, and representatives from the Basin States and the UCRC. Each DOI bureau will provide updates on the status of resources and dam operations. In addition, WAPA will provide updates on the status of the Basin Fund, projected purchase power prices, and its financial and operational considerations. These meetings or calls are intended to provide an opportunity for participants to share and obtain the most up-to-date information on dam operational considerations and the status of resources (including ecological, cultural, Tribal, recreation, and the Basin Fund). One liaison from each Basin State and from the UCRC will be allowed to participate in the monthly operational coordination meetings or calls.

To determine whether conditions are suitable for implementing or discontinuing experimental treatments or management actions, the DOI will schedule implementation/planning meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA, and Reclamation), WAPA, AZGFD, and one liaison from each Basin State and from the UCRC, as needed or requested by the participants. The implementation/planning group will strive to develop a consensus recommendation to bring forth to the DOI regarding resource issues as detailed at the beginning of this section, as well as including WAPA's assessment of the status of the Basin Fund. The Secretary of the Interior will consider the consensus recommendations of the implementation/planning group, but retains sole discretion to decide how best to accomplish operations and experiments in any given year pursuant to the ROD and other binding obligations.

DOI will also continue separate consultation meetings with the Tribes, AZGFD, the Basin States, and UCRC upon request, or as required under existing RODs.

2.2.4.5 Sediment-Related Experiments To Be Evaluated under Alternative D

Under Alternative D, the existing HFE protocol was updated and incorporated into the LTEMP process as specified in Appendix P. Changes to the existing protocol were related to implementation of the new HFEs that are included under Alternative D and an extension of the protocol to the end of the LTEMP period. This new protocol would replace the existing protocol when the LTEMP ROD is issued. Spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period based on the estimated sand mass balance resulting from Paria River sediment inputs during the spring and fall accounting periods, and the dam release pattern during the accounting period. HFE releases would be 1 to 250 hr long and between 31,500 cfs and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December 1 through June 30) or fall (July 1 through November 30) accounting periods and the expected accumulation of sand, the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented.

Sand mass balance modeling would be used to ensure that the duration and magnitude of an HFE are best matched with the mass of sand present in the system during a particular release window. The magnitude and duration of HFEs would not affect the total annual release from Glen Canyon Dam. Reclamation would consider the total water to be released in the water year when determining the magnitude and duration of an HFE.

Sediment-related experiments under Alternative D include (1) sediment-triggered spring and fall HFEs up to 96-hr duration; (2) short-duration (24-hr) proactive spring HFEs in high-volume equalization years prior to equalization releases; and (3) implementation of up to four extended-duration (>96-hr) HFEs, up to 250 hr long, depending on sediment conditions. The pattern of transferring water volumes from other months to make up the HFE volume would be discussed in the monthly Glen Canyon Dam operational coordination meetings described in Section 2.2.4.4.

If sediment resources are stable or improving, the combination of base operations, HFEs, and other treatments would continue as prescribed for Alternative D. If sediment resource conditions decrease to unacceptable levels during the LTEMP period, operations may be modified to the extent allowable under the LTEMP ROD or would be evaluated and considered under a separate NEPA process, potentially including additional studies of sediment augmentation or other actions.

For all sediment experiments, testing would be modified or temporarily or permanently suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or (2) there were unacceptable adverse impacts on resources (Table 2-9). Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted.

Implementation of HFEs would consider resource condition assessments and resource concerns using the annual processes described in Sections 2.2.4.3 and 2.2.4.4. HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3. In addition, there is uncertainty associated with cumulative impacts from sequential HFEs. These cumulative impacts would be considered before implementing an HFE.

Sediment-Triggered Spring HFEs under Alternative D

Under Alternative D, sediment-triggered spring HFEs would be implemented after an initial 2-year delay in order to enable testing of the effectiveness of TMFs, if warranted, and address concerns raised by the apparent positive response of trout to the 2008 spring HFE (Korman, Kaplinski et al. 2011; Melis et al. 2011). Modeling trout response to spring HFEs for the EIS was based on relationships developed from the observed response to the 2008 spring HFE. That modeling also evaluated uncertainty related to the effectiveness of TMFs to control excess trout produced by HFEs. Modeling indicated that even at a relatively low level of effectiveness (10% reduction in trout recruitment), TMFs could effectively reduce the number of trout out-migrants from Glen Canyon to the Little Colorado River reach (RM 61) where humpback chub occur.

After the first 2 years of the LTEMP period, spring HFEs would be implemented when triggered by sediment conditions, except in water years when an extended-duration fall HFE was conducted. Modeling indicates that there may be sufficient sediment input for spring HFEs in about 26% of the years in the LTEMP period. Sediment-triggered spring HFEs would be implemented when triggered during the entire LTEMP period unless new information indicated they were not effective in building sandbars, or there were unacceptable adverse effects on resources (Section 2.2.4.3).

Implementation of a spring HFE would provide important replication of the 2008 spring HFE and aid in understanding the effect of spring HFEs on the trout population. It is possible that the strong 2008 response was a result of the specific conditions present in 2008 (e.g., condition of the food base, trout population size). It is unclear whether implementation under current conditions would produce the same result, and there is a good deal of learning that could result from early implementation. Implementing a spring HFE early in the LTEMP period when chub numbers are relatively high may also be a relatively low-risk option. To provide a means of controlling trout recruitment following tests of spring HFEs, TMFs would be experimentally implemented and tested for efficacy as early in the LTEMP period as possible (see discussion of TMFs below).

Implementation of sediment-triggered spring HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Spring HFEs may not be tested when there appears to be the potential for unacceptable adverse impacts on the resources listed in Section 2.2.4.3. In addition, there is uncertainty associated with the cumulative impacts of sequential HFEs on sediment, aquatic, and potentially other resources. These cumulative impacts would be considered before implementing a spring HFE, particularly if a fall HFE had been implemented in the same water year.

Proactive Spring HFEs under Alternative D

GCMRC scientists identified proactive spring HFEs as a potential experimental treatment to transport and deposit in-channel sand at elevations above those of equalization flows. These HFEs would be tested only in years with high annual water volume (i.e., ≥10 maf), and modeling suggests this would be a relatively rare treatment. A first test would be a 24-hr 45,000-cfs release conducted in April, May, or June. Duration in subsequent tests could be shortened depending on the observed response during the first tests. It would be preferable to test proactive spring HFEs at least two to three times in the 20-year LTEMP period, but being able to do so will be dependent upon annual hydrology. Modeling indicates that proactive spring HFEs would be triggered in about 10% of the years in the LTEMP period.

Proactive spring HFEs would not be tested in the first 2 years of the LTEMP. In addition, proactive spring HFEs would not be tested in years when there had been a sediment-triggered spring HFE or an extended-duration fall HFE earlier in the same water year. Proactive spring HFEs could be performed in the same water year as a 96-hr or shorter sediment-triggered fall HFE, although prior to implementation, the potential effects of these HFEs would be carefully evaluated using the processes described in Sections 2.2.4.3 and 2.2.4.4. The first test would be carefully evaluated to determine whether additional tests were warranted based on the efficacy of building and maintaining sandbars. If initial tests show positive results without unacceptable adverse effects on the resources listed in Section 2.2.4.3, proactive spring HFEs would be implemented when triggered during the entire LTEMP period.

Implementation of proactive spring HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Proactive spring HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources identified in Section 2.2.4.3. The cumulative impacts of sequential HFEs would be considered before implementing a proactive spring HFE.

Sediment-Triggered Fall HFEs under Alternative D

The effects of sediment-triggered fall HFEs on trout recruitment are uncertain, but fall HFEs are expected to have less effect on trout production than spring HFEs. HFEs in November 2012, 2013, and 2014 resulted in little or no increase in the number of YOY trout (VanderKooi 2015; Winters et al. 2016), and this observation may be based on the observed resilience of the food base to disturbance in the fall (Kennedy et al. 2015). However, factors affecting trout response to fall HFEs are not well understood. Modeling for the EIS considered the effect of fall HFEs on trout and modeled fall HFEs in two ways: in one, the effect of fall HFEs was half as long as that of a spring HFE (i.e., it affected trout production only in the water year in which it occurred); in the other, fall HFEs had no effect on trout production. Modeling the effect of fall HFEs in these two ways had an effect on the overall predicted number of trout produced, the number of out-migrants, and ultimately their effect on humpback chub, but the relative performance among alternatives was unchanged.

Modeling indicates fall HFEs would be triggered in about 77% of the years in the LTEMP period. Testing fall HFEs is considered to be a relatively low-risk treatment due to the lack of observed or documented trout response from previous fall HFEs, and would be implemented when triggered during the entire LTEMP period unless new information indicated fall HFEs were not effective in building sandbars, or there were unacceptable adverse effects.

Implementation of sediment-triggered fall HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Fall HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3. The cumulative impacts of sequential HFEs would be considered before implementing a sediment-triggered fall HFE.

Extended-Duration Fall HFEs under Alternative D

Under Alternative D, sediment-triggered fall HFEs with durations longer than 96 hr (up to 250 hr) would be tested. The duration of these extended-duration fall HFEs would be based on the amount of sediment delivered from the Paria River during the fall accounting period and would be no more than the maximum magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling. Based on examination of the observed historical sediment input from the Paria River, it was determined that HFEs up to 10.4 days in length (250 hr) could be supported before exhausting seasonal sediment inputs and affecting water delivery requirements. GCMRC scientists have suggested that increasing the duration of HFEs when sediment supply can support a longer duration may lead to more sand being deposited at higher elevations, resulting in bigger sandbars. Modeling indicates the sediment trigger for this treatment may be reached in 25% of the years in the LTEMP period. There would be no more than four extended-duration fall HFEs over the 20-year LTEMP period.

The duration of the first implementation of an extended-duration HFE would be limited to no more than 192 hr (twice as long as the current limit of 96 hr). This duration is considered long enough to produce a measurable result if the treatment represents an effective approach to building sandbars under enriched sediment conditions. The duration of all tests would be based on available sediment, current hydrology, reviews of available information, the expert opinion of GCMRC and other Grand Canyon scientists, and consideration of potential effects on the resources listed in Section 2.2.4.3. If feasible, monitoring would include real-time observations of sediment concentrations to determine if sediment deposition continues throughout the duration of the extended HFEs.

Implementation of extended-duration fall HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Extended-duration fall HFEs may not be tested when there appears to be potential unacceptable impacts on the resources listed in Section 2.2.4.3. Because the effects of extended-duration HFEs on Lake Mead water quality are a concern, DOI will coordinate with relevant water quality monitoring programs or affected agencies prior to implementing any test of extended-duration HFEs. The cumulative impacts of sequential HFEs would be considered before implementing an extended-duration fall HFE.

Another important concern that results from the large volume of water bypassed is water delivery. Water delivery issues would be considered before deciding to implement an extended-duration fall HFE. An extended-duration HFE would not be implemented if annual release volume would be affected. It is possible that in lower volume years, there would not be sufficient water available to support an extended-duration HFE. A 250-hr extended-duration HFE would result in a monthly total release of approximately 1.2 maf. In lower volume release years (e.g., 7.0 maf or 7.48 maf), the maximum duration may be less than 250 hr. In addition, a sediment-triggered spring HFE or proactive spring HFE would not be conducted in the same water year as an extended-duration fall HFE. If an extended-duration fall HFE was triggered but not implemented for any of the reasons described above, a fall HFE 96 hr or less in duration could be implemented instead. Implementation would necessitate reducing water volume in other months of the same water year.

In order to fully test the efficacy of these longer HFEs, several replicates would be desirable in the 20-year LTEMP period. Extended-duration HFEs would be considered successful and would be continued up to a total of four times in the 20-year LTEMP period as part of an adaptive experimental treatment if there was a widespread increase in bar size relative to ≤96-hr HFEs, and if sand mass balance was not significantly compromised relative to the ability to maintain a long-term equilibrium. Extended-duration HFEs would not continue to be tested if they were not effective in building sandbars, if resulting total sandbar volumes were no bigger than those created by shorter-duration HFEs, or if unacceptable adverse impacts on the resources listed in Section 2.2.4.3 were observed.

2.2.4.6 Aquatic Resource-Related Experiments To Be Evaluated under Alternative D

Under Alternative D, most experimental flow and non-flow actions would be triggered by either estimated numbers of nonnative fish, a combination of estimated numbers of nonnative fish and humpback chub, or measured water release temperature at Glen Canyon Dam, depending on the action under consideration. Humpback chub triggers and nonnative fish triggers were developed during formal Section 7 ESA consultation with the FWS. These triggers may be modified based on experimentation conducted during the LTEMP period.

Aquatic resource experiments that may be tested under Alternative D include (1) TMFs, (2) Tier 1 conservation actions for humpback chub, (3) Tier 2 mechanical removal of nonnative fish, (4) low summer flows in the second 10 years of the LTEMP, and (5) macroinvertebrate production flows. Aquatic resource experiments would seek to refine our understanding of the impacts of water releases, HFEs, and TMFs on these resources. The primary uncertainty surrounding HFEs revolves around the extent to which the seasonality of HFEs or the number of adult rainbow trout determines the strength of rainbow trout recruitment.

Experimental nonnative fish control actions would be implemented if the humpback chub population declined, and proactive conservation actions had failed to reverse declining populations. Two different tiers of population metrics would be used to trigger responses, including actions to increase growth and survival of humpback chub (Tier 1) and mechanical removal of nonnative fish (Tier 2), which would only be implemented when Tier 1 actions fail to slow or reverse the decline in the humpback chub population. This tiered approach and the triggers that would be used to implement it are described below and in the LTEMP Biological Assessment and BO presented in Appendix O.

For all aquatic resource experiments, testing would be modified or temporarily or permanently suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or (2) there were potential unacceptable adverse impacts on the resources listed in Section 2.2.4.3. Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted.

Implementation of aquatic resource experiments would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Aquatic resource experiments may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

Trout Management Flows under Alternative D

TMFs (described in Section 2.2.3.2) are a potential tool that could be used to control annual trout production in the Glen Canyon reach for purposes of managing the trout fishery and for limiting emigration from the Glen Canyon reach to Marble Canyon and the Little Colorado River reach. If resource conditions are appropriate, TMFs may be tested under Alternative D early in the experimental period, preferably in the first 5 years. These first tests could be triggered by modeled trout recruitment levels or otherwise implemented to test the effectiveness of TMFs.[6] The intent of these early tests would be to determine the effectiveness of TMFs and a best approach to trout management. If TMFs are determined to be effective for controlling trout numbers while minimizing impacts on other resources, they may be deployed as an adaptive experimental treatment triggered by estimated trout recruitment.

It should be noted that several Tribes have expressed concerns about TMFs as a taking of life within the canyon without a beneficial use. The Pueblo of Zuni has expressed concern that the taking of life by trout stranding has an adverse effect on the Zuni value system. The joint-lead agencies will continue to work with the Tribes regarding options for trout management, and to determine the most appropriate means of mitigating impacts on Tribal values if TMFs are implemented.

As many as three TMF cycles/month (see Section 2.2.3.2) in a period of up to 4 months during May through August could be tested, depending on the results of early tests. Aspects of TMF design that would be investigated include:

- Duration of high flows needed to lure YOY rainbow trout into near-shore habitats,
- Magnitude of the high flow that would be more effective in luring YOY trout to near-shore habitats,
- Whether or not moving to high flows first is needed to reduce YOY trout numbers (as opposed to simply dropping rapidly from normal flows to minimum flows),
- Timing of TMF cycles during the May–August period of trout emergence, and
- Number of cycles necessary to effectively limit trout recruitment.

If TMFs prove to be effective in controlling trout production and emigration to the Little Colorado River reach, and they become an integral part of the LTEMP, regular implementation of TMFs may need to include variable timing to prevent adaptation of the population to specific timing (e.g., increase in recruitment by fall-spawning rainbow trout).

Certain aspects of TMF effectiveness can be addressed through observational studies (e.g., the number of YOY rainbow trout observed in the near-shore environment in daily increments after the high flow is initiated);[7] others may be addressed through consideration of the physical environment in Glen Canyon (i.e., what areas are inundated or exposed at different

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[6] The decision to conduct TMFs in a given year would consider the resource conditions as specified in Section 2.2.4.3 and would also involve considerations regarding the efficacy of the test based on those resource conditions.

[7] Because older age classes of trout tend to occupy deeper habitats toward the middle of the river channel, they are less susceptible to stranding and are less likely to be directly affected by TMFs.

flows). Ultimately, however, effectiveness would be judged based on comparison of fall trout recruitment estimates to expectations based on prior years. It may take several years to make this determination, depending on the strength of the response and the type of TMFs tested. Ultimately, however, effectiveness would be based on the ability of TMFs to reduce recruitment in and emigration from the Glen Canyon reach. The driving forces behind emigration are not fully understood, but are expected to be related to population size and food base in the Glen Canyon reach.

For the EIS modeling, a trigger of 200,000 YOY trout was used to determine when TMFs would be implemented. A regression equation based on annual volume, the variability in flows from May through August, and the occurrence of a spring HFE was used to predict the number of YOY. The actual trigger used could be higher or lower depending on the results of experiments that will be conducted on the effectiveness of TMFs. In addition, the predictive regression equation could be modified based on new information. The trigger and predictive equation used would be modified as needed in an adaptive management context utilizing the process described in Section 2.2.4.3. Triggers for implementation of TMFs would also be developed in consultation with the AZGFD and other entities as appropriate.

Monitoring of other resources, particularly food base and the physiologic condition of adult rainbow trout, would also be considered. In addition, the number of YOY trout at the end of the summer would be estimated to determine if it equals or exceeds the estimated number of recruits needed to sustain the desired number of adult trout. If the estimated number of recruits is less than the recruitment target, TMFs would be re-evaluated for modification before implementation in subsequent years. It is anticipated that the trout population could rebound from a 1-year drop below this target level.

As discussed in relation to sediment experiments above, there is concern among scientists and stakeholders with regard to the risk associated with implementation of spring HFEs as related to trout response and subsequent effects on the humpback chub population. For this reason, TMFs would be implemented and tested for effectiveness as early in the LTEMP period as possible, preferably before the first spring HFEs are triggered, even if not triggered by high trout recruitment. TMFs could be implemented in years that feature a spring HFE and in the water year that follows an equalization flow because of the expected positive effects of equalization on rainbow trout recruitment. Any implementation of TMFs would consider the status of the trout fishery prior to implementation. Modeling indicates TMFs would be triggered by trout recruitment numbers in 32% of the years in the LTEMP period.

There is potential for confounding effects when coupling TMFs with HFEs. If trout recruitment is still high after implementation of TMFs that follow HFEs, this would suggest TMFs were not effective as designed for that trial. If recruitment is lower than expected after TMF implementation, however, uncertainty will remain about whether an HFE failed to stimulate trout recruitment or whether TMFs were effective in suppressing otherwise strong recruitment. It may not be necessary to determine the underlying effect on trout numbers unless TMFs have undesirable side effects on other resources or the trout population.

If TMFs are found to be highly effective in controlling trout recruitment and emigration of trout, and emigration only occurs or primarily occurs immediately following high recruitment years, it may be possible to limit TMF implementation and achieve multiple resource goals, particularly if unintended impacts of TMFs on other resources such as native fish become evident. Timing of TMFs may also be adjusted based on the best scientific information available related to trout emigration behavior. If adverse impacts of TMFs become evident, this may also suggest revisiting whether or not TMFs are necessary in response to spring HFEs. Lastly, if, there is an observed increase in trout recruitment due to fall HFEs, then application of TMFs in the spring following a fall HFE would be considered.

Implementation of TMFs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. TMFs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

Tier 1 Conservation Actions for Humpback Chub under Alternative D

Tier 1 conservation actions designed to improve rearing and recruitment of juvenile humpback chub would be implemented if the combined point estimate for adult (≥200 mm) humpback chub in the Colorado River mainstem Little Colorado River aggregation (RM 57–RM 65.9) and in the Little Colorado River falls below 9,000 (2,000 in the mainstem and 7,000 in the Little Colorado River), as estimated by the currently accepted humpback chub population model, or if recruitment of subadult (150 mm–199 mm) humpback chub does not meet or exceed estimated adult mortality (Appendix O). Tier 1 actions would include expanded translocations of YOY humpback chub within the Little Colorado River to areas within the river that have relatively few predators (i.e., above Chute Falls, Big Canyon), or larval fish would be taken to a rearing facility and released in the Little Colorado River inflow area once they reach 150 mm to 200 mm. In addition to these translocation activities, 300 to 750 larval or YOY humpback chub would be collected from the Little Colorado River and reared in a fish hatchery to less vulnerable sizes before releasing them. Once these fish reach 150 mm to 200 mm, they would be translocated to the Little Colorado River in the following year.

Tier 2 Mechanical Removal of Nonnative Fish under Alternative D

Mechanical removal of nonnative fish in the Little Colorado River reach (potentially from RM 50–RM 66) would be conducted if the Tier 1 conservation actions described in the previous section were not successful in halting a decline in the number of adult humpback chub. Mechanical removal, using the methods described in Section 2.2.1 and Appendix O, would be conducted if the point estimate of adult humpback chub falls below 7,000 (the trigger level used in Reclamation 2011b), as estimated by the currently accepted humpback chub population model. Up to six monthly removal trips (February through July) would be implemented in each year triggered.

Mechanical removal would stop if the "predator index" is depleted to less than 60 rainbow trout/km (see Appendix O) for at least 2 years in the reach between RM 63 and RM 64.5, and immigration rate is low, or the adult humpback chub population estimates exceed 7,500, and recruitment of subadult chub exceeds adult mortality for at least 2 years. The predator index calculates predator densities by incorporating additional species, in addition to rainbow trout, and makes assumptions about their relative predation rates compared to rainbow trout. For example, brown trout are estimated to be about 17 times more predacious on humpback chub than are rainbow trout (Ward and Morton-Starner 2015). Additional predators (e.g., smallmouth bass) could be included based on their piscivory level relative to that of rainbow trout.

If humpback chub adult numbers continue to decline and Tier 1 and Tier 2 actions are not working, FWS, in coordination with Reclamation, NPS, and the Tribes, will consider other actions to stop the decline. Triggers will be reviewed and modified as necessary, and actions and triggers will be modified if humpback chub are found to be affected by other factors.

Implementation of mechanical removal would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4.

The DOI recognizes that lethal mechanical removal is a concern for Tribes, particularly the Hopi Tribe and Pueblo of Zuni, because it is a taking of life in the canyon without a beneficial use. (See Sections 3.5.3.4 and 4.9.1.3 for more information regarding concerns of the Tribes.) Reclamation had committed in agreements with the Tribes in 2012 to consider live removal when feasible (Reclamation 2012b); however, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters. Reclamation and NPS have worked with the Tribes to determine a beneficial use of the removed fish on other projects and understand that what is considered beneficial use may not be the same for all Tribes. Reclamation and NPS are committed to consult further with the Tribes to determine acceptable mitigation for nonnative fish control.

Low Summer Flows under Alternative D

Low summer flows could be considered a potential tool for improving the growth and recruitment of young humpback chub if temperature had been limiting these processes for a period of years. Low summer flows may lead to warmer water temperatures in the Little Colorado River reach and farther downstream, as well as contribute to enhanced growth rates of young humpback chub. There are also potential negative effects from low summer flows on several resources such as hydropower, sediment, water quality, vegetation, and recreation. Low summer flows may also negatively affect humpback chub due to an increase in warmwater nonnative fish or a decrease in the aquatic food base. There was one test of low steady summer flows below Glen Canyon Dam in 2000; however, the results relative to humpback chub were not conclusive (Ralston et al. 2012).

Because of the uncertainty related to the effects of low summer flows on humpback chub, other native fish, warmwater nonnative fish, water quality, and potentially other resources, DOI will ensure that the appropriate baseline data are collected throughout the implementation of the

LTEMP. In addition, DOI will convene a scientific panel that includes independent experts prior to the first potential use of low summer flows to synthesize the best available scientific information related to low summer flows. The panel may meet periodically to update the information, as needed. This information will be shared as part of the AMWG annual reporting process.

It is thought that the potential benefit of an increase in temperature could be greatest if a water temperature of at least 14°C could be achieved, because these warmer temperatures could favor higher humpback chub growth rates (nearly 60% higher). For comparison, the July through September growth increments of YOY humpback chub are estimated to be 4, 7, 11, 14, and 17 mm at temperatures of 12, 13, 14, 15, and 16°C, respectively, based on a growth-temperature regression in Robinson and Childs (2001). Note that reduction in summer flows would necessitate increasing flows in other months relative to base operations (Table 2-10; Figure 2-22).

If tested, low summer flows would occur for 3 months (July, August, and September), and only in the second 10 years of the LTEMP period. The duration of low summer flows could be shortened to less than 3 months in successive experiments if supported by the scientific panel described above or based on the scientific data and observed effects. The probability of triggering a low summer flow experiment is considered low (about 7% of years), because the water temperature conditions that would allow such a test occur infrequently (see Appendix D).

TABLE 2-10 Flow Parameters for a Year with Low Summer Flows under Alternative D in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	5,783
November	642	0.0780	10,781	5,774
December	716	0.0870	11,643	6,443
January	764	0.0928	12,423	6,874
February	675	0.0820	12,153	6,074
March	691	0.0840	11,245	6,223
April	859	0.1044	14,433	7,730
May	851	0.1034	13,841	7,659
June	930	0.1130	15,631	8,000
July	492	0.0598	8,000	2,000
August	492	0.0598	8,000	2,000
September	476	0.0578	8,000	2,000

[a] Within a year, monthly operations may be increased or decreased based on factors referenced in Section 2.2.4.2.

[b] Values have been rounded.

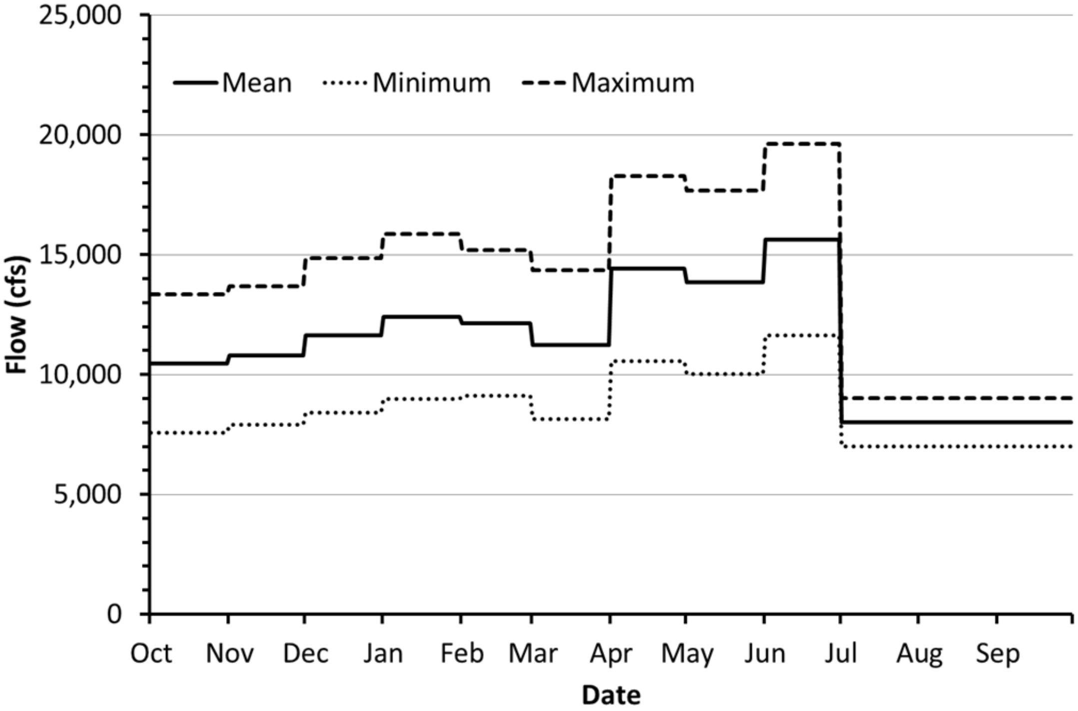

FIGURE 2-22 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative D in an 8.23-maf Year Based on the Values Presented in Table 2-10

Low summer flows would only be implemented in years when the projected annual release was less than 10 maf, and if the temperature at the Little Colorado River confluence was below 14°C without low summer flows, and the release temperature was sufficiently high that 14°C could be achieved at the Little Colorado River with the use of low summer flows.

The ability to achieve target temperatures at the Little Colorado River confluence by providing lower flows is dependent on release temperatures, which are in turn dependent on reservoir elevation. For example, using the temperature model of Wright, Anderson et al. (2008) in an 8.23-maf year, release temperatures of 10.8°C, 11.0°C, and 11.7°C would be needed in July, August, and September, respectively, to achieve a target temperature of 14°C at the Little Colorado River confluence at flows of 8,000 cfs.

Release temperatures fall into three categories for any temperature target: (1) too low to achieve the target temperature at the Little Colorado River even at low flow; (2) high enough to achieve the target temperature at the Little Colorado River only if low flows (5,000 cfs to 8,000 cfs) are provided; and (3) high enough to achieve target temperature at the Little Colorado River regardless of the flow level. Low summer flows would only be triggered in years that fell into the second category.

Implementation of a low summer flow experiment is complicated by two factors: the earliest date at which it could be determined that a target temperature of at least 14°C could be achieved in all 3 months, and the ability to release the remaining annual volume once that determination is made. The earliest time a determination could be made would be in early April of each year, and it would be based on the April 1 forecast of reservoir elevation. Because low summer flows could be implemented in the 3 months at the end of the water year, it is possible that by the time a determination was made to conduct a low summer flow experiment, it may not be possible to release enough water in the remainder of the spring to compensate for the low flow period. A low summer flow experiment would only be tested in years when performing the experiment would not result in a deviation from the annual Glen Canyon Dam release volumes made pursuant to the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

A first test of low summer flows would feature low flows of 8,000 cfs and relatively little fluctuation (±1,000 cfs per day). Depending on the results of the first test with regard to warming and humpback chub response, the magnitude of the low flow could be adjusted up or down (as low as 5,000 cfs), and the level of fluctuation also modified up to the range allowed under Alternative D (i.e., 10× monthly volume [in kaf] in July and August, and 9 × monthly volume [in kaf] in September).

The first test of low summer flows will be determined to be successful or unsuccessful for humpback chub based on input from an independent scientific panel review. If the first test was determined to be unsuccessful (and it was determined to have been implemented without major confounding factors), then additional tests would not be performed. Low summer flows would be considered successful if it can be determined that they produced sufficient growth of YOY humpback chub and that growth resulted in an increase in recruitment, but avoided unacceptable increases in warmwater nonnative fishes, trout, or aquatic parasites, or resulted in unacceptable adverse impacts on other aquatic resources. If it was determined to be successful, then additional low summer flows would occur only when humpback chub population concerns warranted them and water temperature has been colder for a period of years, and the desired warming could be achieved only with low summer flows. The temperature target could be adjusted 1°C higher based on the results of the first test or the limitations between predicted and measured temperatures.

Implementation of low summer flows would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Low summer flows may not be conducted in years when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

The effects of low summer flows on Lake Mead water quality are an identified concern. DOI will coordinate with relevant water quality monitoring programs or affected agencies prior to implementing any test of low summer flows. There are additional concerns related to the risk of warmwater nonnative fish expansion or invasion (e.g., the elevation of Lake Mead was high or the number of warmwater nonnative fish was high). These issues are potential off-ramps as described in Section 2.2.4.3 using the process described in Section 2.2.4.4.

Macroinvertebrate Production Flows under Alternative D

A more diverse and productive aquatic food base could benefit a variety of priority resources, including native fish (including the endangered humpback chub), the rainbow trout fishery, and other riparian species that occur in Glen, Marble, and Grand Canyons. Mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), collectively referred to as EPT, are important components of a healthy aquatic food base, but they are notably absent from the Glen and Marble Canyon reaches and very low in abundance and diversity in the Grand Canyon. GCMRC has hypothesized that EPT taxa are recruitment limited, because daily flow fluctuations to meet hydropower demand cause high egg mortality, and the absence of EPT has an adverse effect on the carrying capacity and condition of the trout fishery and native fish communities. EPT are thought to be recruitment limited because Glen Canyon Dam fluctuations create a large varial (intermittently wetted) zone along shorelines. Because the Colorado River in Glen, Marble, and Grand Canyons is canyon-bound and the tributaries that join the river all have comparatively low flow, the size of the varial zone does not appreciably decrease with distance downstream. Thus, although water temperature regimes become more naturalized with distance downstream, the effect that daily flow fluctuations to meet hydropower demand have on the stability of shoreline habitat does not attenuate much with distance from the dam.

This hypothesis attributes the absence of EPT and the poor health of the invertebrate assemblage to the width of the varial zone, similar to earlier investigations (Blinn et al. 1995), but focuses on the effects unstable shorelines have on the eggs of these species. This hypothesis assumes that egg-laying by EPT occurs principally along shorelines. According to the hypothesis, EPT taxa downstream of Glen Canyon Dam are recruitment limited, because daily flow fluctuations to meet hydropower demand negatively affect habitat quality along the shorelines where egg laying is assumed to occur.

To test this hypothesis, macroinvertebrate production flows would be provided every weekend from May through August (34 days total).[5] The flow on weekends would be held steady at the minimum flow for that month, which would ensure that the insect eggs laid during weekends would remain submerged throughout larval development. If the hypothesis is true, there would be an increase in insect production due to the reproductive success of insects that laid eggs during weekends. No change in monthly volumes, ramping rates, or the maximum daily range in flow during weekdays would be required for this experiment. To offset the smaller water releases that would occur during weekends within a given month, larger releases would need to occur during the weekdays within a given month.

Implementation of macroinvertebrate production flows would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. These flows may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

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[5] The duration and other characteristics of experimental macroinvertebrate production flows could be adjusted within the range of the analysis based on the results of initial experiments.

Effects of the tests would be evaluated using observation to determine the location where insect eggs are deposited and the emergence rates of species. Depending on the outcome of the tests, the experiment could be discontinued if there were unacceptable effects on other resources. There is also the possibility that implementation would result in confounding interactions with TMF experiments, and this will be discussed during the communication and consultation process as described in Section 2.2.4.4.

2.2.4.7 Conservation Measures under Alternative D

Applicable conservation measures identified in previous BOs related to Glen Canyon Dam operations would be carried forward in Alternative D and are described fully in Appendix O. Additional conservation measures to minimize or reduce the effects of actions under Alternative D, or that benefit or improve the status of listed species as part of the LTEMP, also are described in Appendix O.

2.2.5 Alternative E

The objective of Alternative E is to provide for recovery of the humpback chub while protecting other important resources including sediment, the Glen Canyon rainbow trout fishery, aquatic food base, and hydropower resources. Alternative E features a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions (Table 2-2). The alternative uses decision trees to identify when a change in base operations or some other action is needed to protect resources. Of particular focus under Alternative E are changes in sediment input, humpback chub numbers and population structure, trout numbers, and water temperature. The Basin States submitted this alternative for analysis and consideration in the LTEMP EIS.

Some aspects of Alternative E originally proposed by the Basin States were not included in the alternative evaluated in the EIS. These include new infrastructure in the form of a pump-back system that would be used to pump water from the mainstem Colorado into the Paria River to mobilize fine sediment that would then flow into the Colorado River and increase turbidity to reduce the predation efficiency of trout on young humpback chub. The Basin States also proposed implementation of rapid-response HFEs that would be implemented by timing high releases from Glen Canyon Dam to coincide with sediment inputs from the Paria River. See Section 2.4 for a discussion of elements considered but dismissed from analysis in the LTEMP EIS.

2.2.5.1 Base Operations under Alternative E

Under Alternative E, monthly volumes would closely follow the monthly hydropower demand as defined by the contract rate of delivery (Table 2-11). The total monthly release volume of October, November, and December, however, would be equal to that under Alternative A (i.e., 2 maf in years with ≥8.23 maf annual release volume) to minimize the

TABLE 2-11 Flow Parameters under Alternative E in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	6,426
November	642	0.0780	10,781	6,415
December	716	0.0870	11,643	7,159
January	781	0.0949	12,707	7,813
February	691	0.0840	12,449	6,914
March	730	0.0887	11,870	7,298
April	650	0.0790	10,922	6,499
May	672	0.0817	10,935	6,724
June	704	0.0855	11,829	8,446
July	767	0.0932	12,471	9,202
August	659	0.0801	10,721	7,911
September	575	0.0699	9,668	5,753

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts or other factors, and based on application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

possibility of the operational tier differing from that of Alternative A, as established in the Interim Guidelines (Reclamation 2007a). In addition, lower monthly volumes (relative to Alternative A) would be targeted in August and September (15% of the annual release volume for August and September combined) to reduce sediment transport during the monsoon period, when most sediment is delivered by the Paria River.

Under base operations, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to the volume of water scheduled to be released during the month (12 × monthly volume in kaf in high power demand months of June, July, and August, and 10 × monthly volume in kaf in other months; Table 2-1; Figure 2-23). For example, the daily fluctuation range in July with a scheduled release volume of 800 kaf would be 9,600 cfs, and the daily fluctuation range in December with the same scheduled release volume would be 8,000 cfs. The down-ramp rate under this alternative would be limited to no greater than 2,500 cfs/hr, which is 1,000 cfs/hr greater than what is allowed under Alternative A. The up-ramp rate would be 4,000 cfs/hr, and this is the same as under Alternative A. Figure 2-23 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-24 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative E. Figure 2-25 shows details of hourly flows during a week in July.

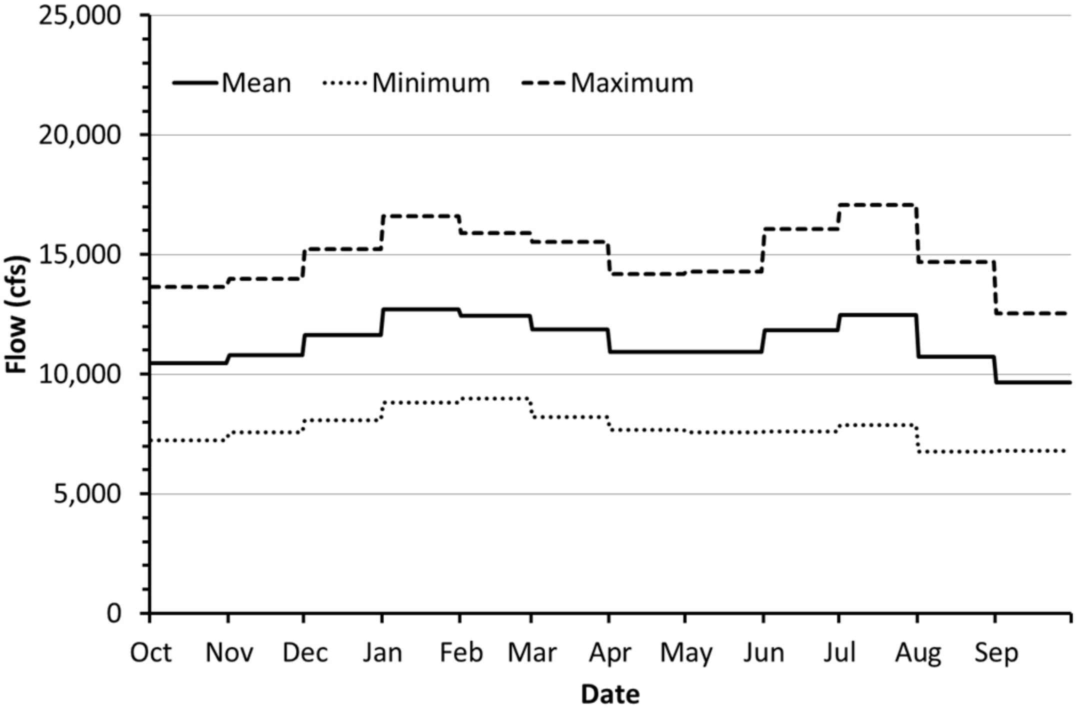


FIGURE 2-23 Mean, Minimum, and Maximum Daily Flows under Alternative E in an 8.23-maf Year Based on the Values Presented in Table 2-11

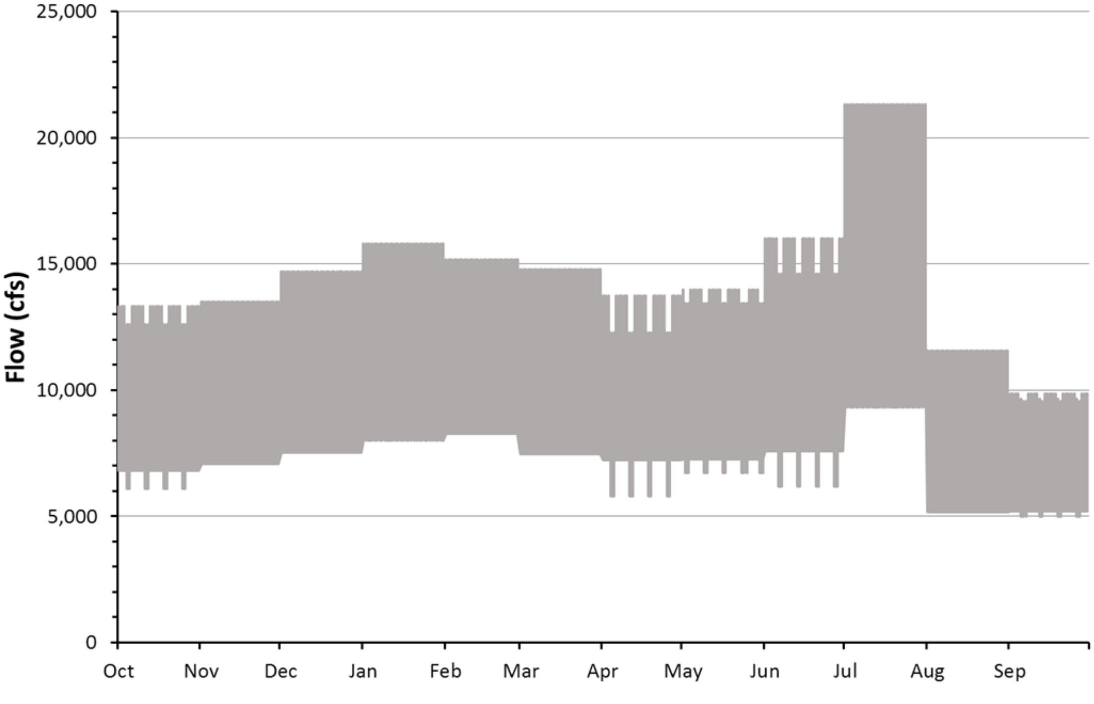


FIGURE 2-24 Simulated Hourly Flows under Alternative E in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-23. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

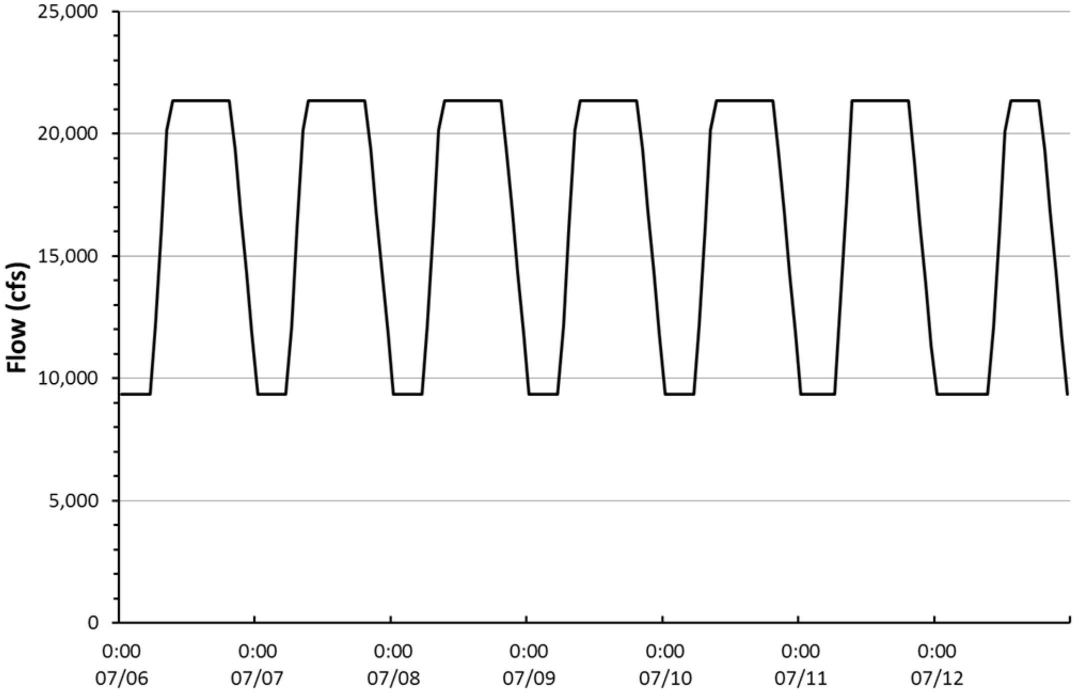
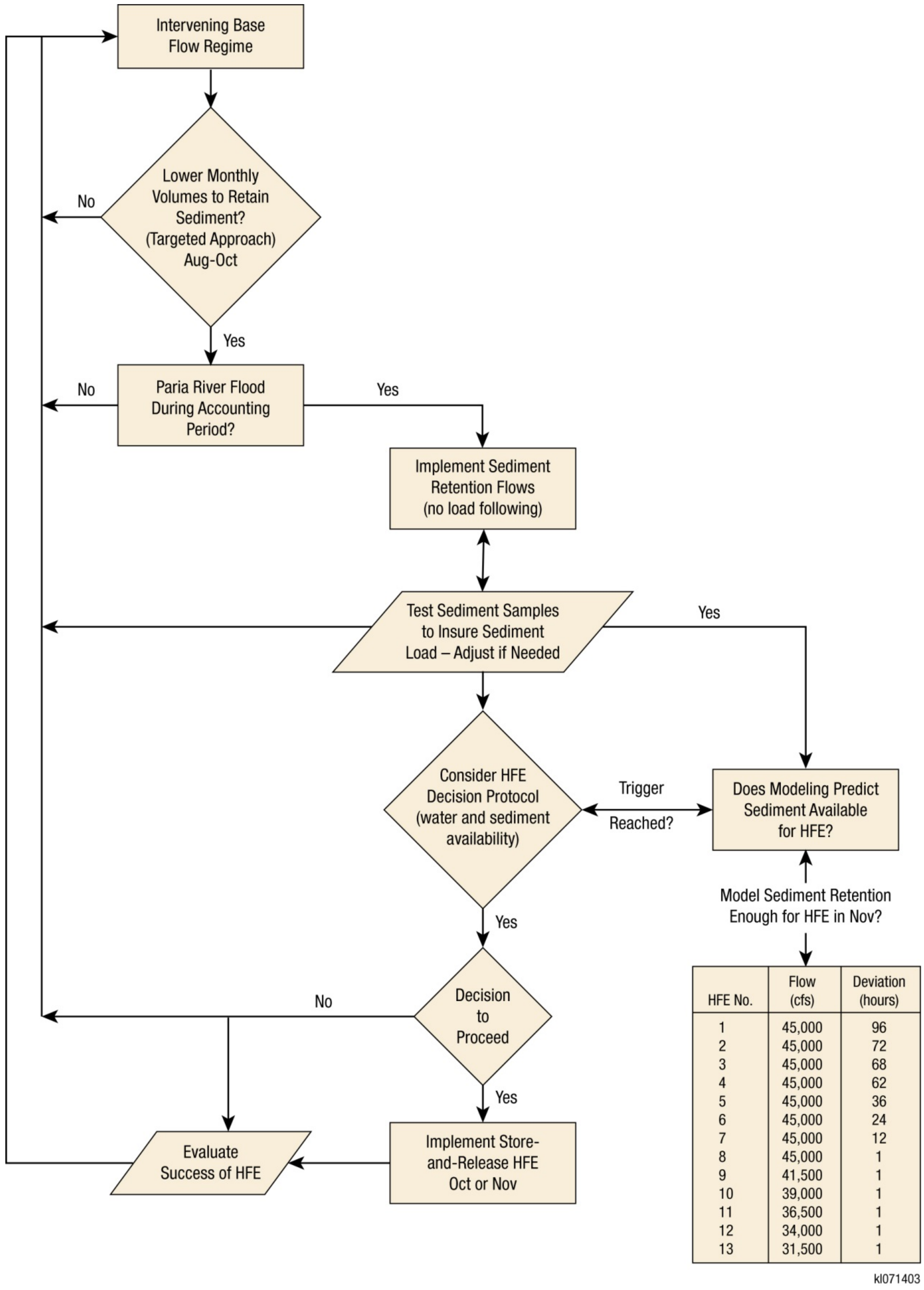


FIGURE 2-25 Simulated Hourly Flows under Alternative E for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

2.2.5.2 Experimental Framework for Alternative E

Alternative E uses a condition-dependent approach to implement experimental elements. The alternative would use decision trees, tied to information collected under a long-term monitoring program that would be implemented annually to determine operations and flow and non-flow actions in a given year (Figures 2-26 and 2-27). In general, the experimental framework considered under Alternative E is more structured than that proposed under other alternatives, especially for the experimental evaluation of TMFs. Alternative E would incorporate a 2 × 2 factorial science design to test TMFs.

Base operations under Alternative E would be experimentally modified in response to changes in resource conditions or the need for equalization as specified under the 2007 Interim Guidelines (Reclamation 2007a). The most important experiments relate to (1) implementation of HFEs in response to sediment inputs; (2) reductions in fluctuation in certain parts of the year in response to sediment inputs; and (3) reductions in flows in certain years from July through September to provide warmer water for humpback chub near the confluence with the Little Colorado River. Non-flow actions are largely limited to those that are common to all alternatives as described at the beginning of Section 2.2.



HFE No.	Flow (cfs)	Deviation (hours)
1	45,000	96
2	45,000	72
3	45,000	68
4	45,000	62
5	45,000	36
6	45,000	24
7	45,000	12
8	45,000	1
9	41,500	1
10	39,000	1
11	36,500	1
12	34,000	1
13	31,500	1

FIGURE 2-26 Decision Tree for Sediment-Related Actions under Alternative E (modified from Figure 1 in original Basin States submittal)

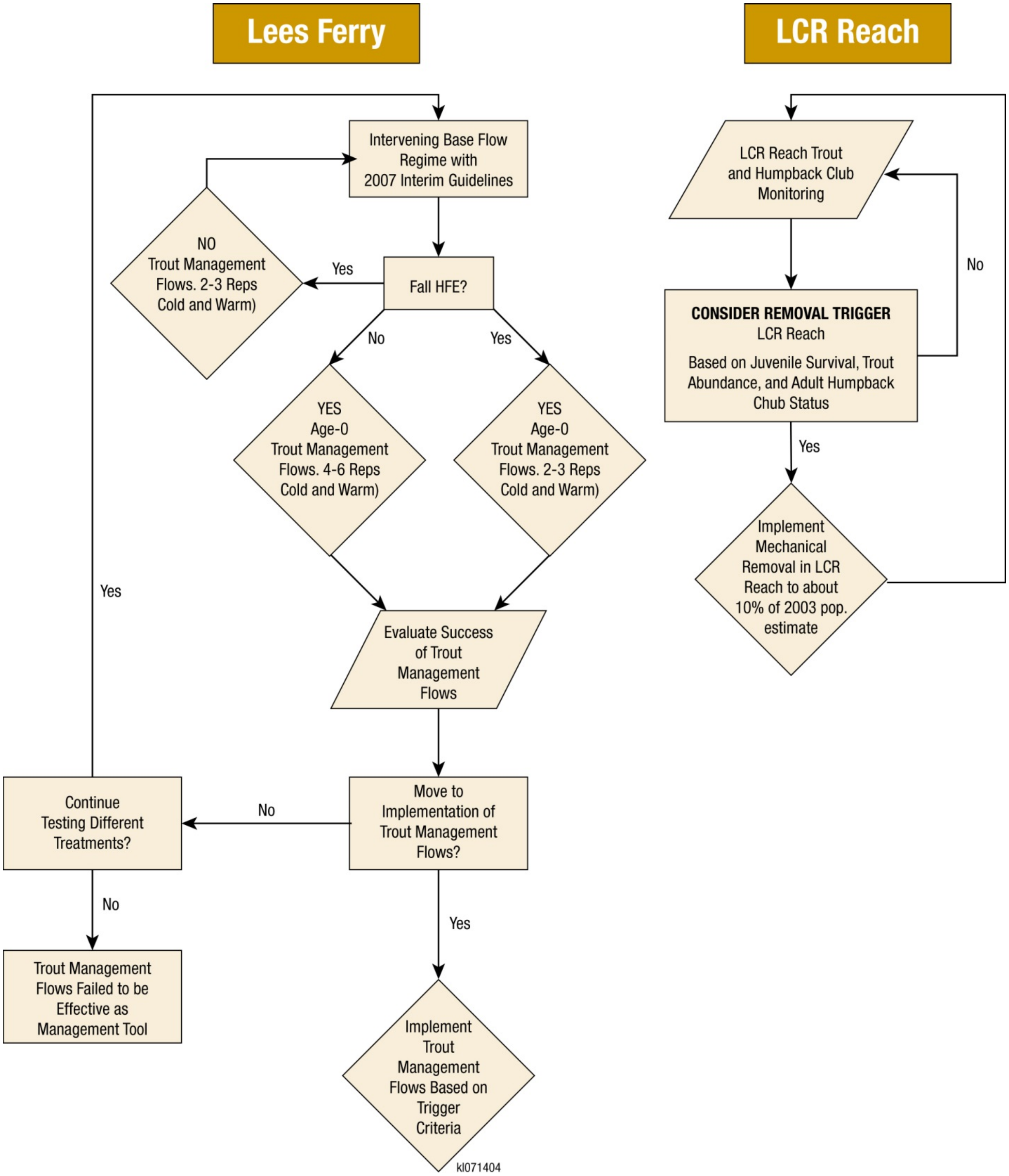


FIGURE 2-27 Decision Tree for Trout-Related Actions under Alternative E (Figure 2 in original Basin States submittal)

Sediment-Related Experiments To Be Evaluated under Alternative E

Under Alternative E, the HFE protocol would be incorporated into the LTEMP process and extended to the end of the LTEMP period. Spring and fall HFEs would be implemented when triggered using the same Paria River sediment input thresholds used under the existing HFE protocol (Reclamation 2011b). HFE releases would be 1 to 96 hr long and between 31,500 cfs and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December through March) or fall (July through October) accounting periods, the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented (see Section 2.2.1 for a brief description of the existing HFE protocol).

Under Alternative E, only fall HFEs would be conducted during the first 10-year period. This delay of implementation of spring HFEs is intended to allow for the testing of TMFs to control trout numbers and emigration rates, and is based on the response of the trout population to the spring HFE of 2008.

Under Alternative E, daily fluctuations for load-following would be reduced (except for instantaneous increases or decreases in flow to provide regulation services)[6] after significant sediment input (sufficient input to trigger an HFE) from the Paria River in August, September, or October to increase the amount of sediment available for transport and deposition by fall HFEs. These reduced fluctuations would occur until an HFE was implemented or a decision to not implement an HFE was made. Under Alternative E, within-day fluctuations in hourly flows would be reduced to a within-day range of 2,000 cfs (i.e., ±1,000 cfs of the mean daily flow).

During high-volume (≥10-maf release volume) release years (i.e., equalization years), an HFE would be conducted quickly (i.e., days) following an unusually large input of sediment from the Paria River to redistribute the new sediment from the main river channel before high-volume releases can transport it downstream. This “quick response” HFE is different from the proactive spring HFEs proposed under Alternatives C and D because it is sediment-triggered; could occur in the spring, summer, or fall of the year; and would not be limited in duration to 24 hr.

Aquatic Resource-Related Experiments To Be Evaluated under Alternative E

Mechanical removal of trout would be conducted at the confluence of the Little Colorado River under certain conditions (i.e., low survival rate of juvenile humpback chub, trout abundance exceeds the level seen in 2003 of about 6,900 individuals in the Little Colorado River reach (RM 56.3 and RM 65.7), or the number of humpback chub adults drops by 1,000 individuals (during the same time the abundance of trout exceeds 690 in the same reach). The removal protocol would follow the Nonnative Fish Control protocol (Reclamation 2011a).

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[6] Although instantaneous changes in flows could occur within an hour to provide for regulation services, these flow changes would not affect the mean hourly flow.

Alternative E would evaluate potential methods for using releases (TMFs) from Glen Canyon Dam to reduce production of YOY rainbow trout to improve the quality of the Glen Canyon trout fishery and potentially help conserve humpback chub and other native fishes.

This strategy has two potential benefits: (1) flow manipulations are likely to be much less expensive and intrusive than large-scale mechanical removal efforts downstream, and (2) trying to manage trout densities in the Little Colorado River reach without reducing trout production upstream will be difficult to overcome during years with high production (e.g., trout response to 2008 HFE and response to 2011 high steady flows). The goal is to develop a management action based on condition-dependent criteria. Key metrics for a high-quality trout fishery would need to be developed in consultation with the AZGFD, such as targets for adult and juvenile numbers, individual fish condition, YOY numbers, and information and value determined through creel surveys. TMFs could be used to help attain these goals with other management tools employed by the AZGFD and NPS. TMF treatments should address the following:

- Evaluate the potential for utilizing changes in down-ramp rates to strand or displace juvenile trout and reduce recruitment,
- Evaluate different types and magnitudes of TMFs, and
- Determine whether flow and non-flow actions at Lees Ferry would be effective in improving the Lees Ferry trout fishery.

TMFs would be tested in a 2 × 2 factorial design with HFEs over a 20-year period to evaluate their potential effectiveness in reducing trout recruitment levels in the Glen Canyon reach over a variety of environmental conditions. The status of the trout fishery would be considered in any decision to proceed with implementation of TMFs in a given year. The goal is to develop management tools that are robust to a range of natural and human caused conditions. The following treatment combinations would be implemented with a goal of achieving two to three replicates for each combination under warm and cold temperature conditions over the 20-year LTEMP period:

- No fall HFE and no TMF, to measure trout recruitment with neither factor in place;
- No fall HFE, but with a TMF, to test effects of TMFs alone;
- Fall HFE, but no TMF, to test effects of HFEs alone; and
- Both fall HFE and TMF, to test the effects of both in the same year.

Two options for implementation would be considered (1) begin with moderate treatments (e.g., one cycle); or (2) begin with more robust treatments (e.g., three or more cycles) to establish easily observable results. With this latter approach, successive treatments would evaluate more moderate treatments if the first tests showed an effect.

At least four types of TMFs would be evaluated: (1) YOY stranding and displacement flows from May through June, (2) YOY stranding and displacement flows from July through August, (3) YOY stranding and displacement flows without moving to high flows (e.g., 20,000 cfs) prior to dropping to a minimum, and (4) flow reductions applied only at night to the above scenarios with the objective of reducing food base impacts from desiccation.

YOY stranding and displacement flows would consist of 3 days at steady 20,000 cfs followed by a rapid drop (unrestricted down-ramp rate) to 5,000 cfs or 8,000 cfs to be held for 6 hr during daylight hours (6 a.m.–noon). Three such cycles would be conducted over the month. A 3-day flow cycle would be followed by 7 days of normal flows, and this 3- to 7-day pattern would be repeated three times over the month. This option would include tests of this method in May and June, and then in July and August if sediment retention flows were not in effect (see Figure 2-15 for an illustration of TMFs).

A test without moving to high flows first would determine if it is necessary to attract trout to higher elevations (e.g., steady 20,000 cfs) before a rapid drop. Trout generally reside at the normal minimum flow (Korman and Campana 2009). Thus, they may be susceptible to a rapid drop in flow without the need to raise flows for an extended period beforehand. This test would stabilize flows near the normal minimum (within the varial zone), and would then apply a rapid down-ramp below the minimum.

If reservoir elevations are not variable enough during the first 10 years to produce years with warm releases, a steady flow test aimed at achieving warmer temperatures would be considered. If the evaluation is warranted, implementation would be conditioned on the status of the humpback chub and other critical resources. A low summer flow experiment would not be conducted at a time when the humpback chub population is low or declining. Under Alternative E, a low summer flow experiment would only be conducted in a warm release year to increase contrast with more typical coldwater years.

The transition in flow volume from one month to the next can be substantial. Low-volume months, such as a 600-kaf month, can be followed by a month that exceeds 900 kaf. These large transitions may have a negative impact on productivity of the aquatic food base (i.e., organisms including algae, plants, and invertebrates that serve as the foundation of the aquatic food web). Alternative E would include a stepped transition between months when substantial differences in the amount of water releases occur. The decision rules for transition flows would need to be developed to take into account the difference in volume that would trigger these flows, and the amount of time necessary to provide suitable transition to minimize impacts on the food base.

2.2.6 Alternative F

The objective of Alternative F is to a provide flows that follow a more natural pattern while limiting sediment transport and providing for warming in summer months. In keeping with this objective, Alternative F does not feature some of the flow and non-flow actions of the other alternatives.

Flows under Alternative F would follow the same basic monthly pattern as the Seasonally Adjusted Steady Flow Alternative in the 1995 EIS (Reclamation 1995), but the pattern is modified to achieve higher, more variable spring peak flows, lower summer, fall, and winter flows, and warmer temperatures starting in July. Peak flows would be lower than pre-dam magnitudes to reduce sediment transport and erosion given the reduced sand supply downstream of the dam. There would be no within-day fluctuations in flow under Alternative F (see Tables 2-1 and 2-12; Figure 2-28).

Under Alternative F, peak flows would be provided in May and June, which corresponds well with the timing of the pre-dam peak. The overall peak flow in an 8.23-maf year would be 20,000 cfs (scaled proportionately in drier and wetter years); it would include a 24-hr 45,000-cfs flow at the beginning of the spring peak period (e.g., on May 1) if there was no triggered spring HFE in the same year, and a 168-hr (7-day) 25,000 cfs flow at the end of June. Following this peak, there would be a rapid drop to the summer base flow. The initial annual 45,000-cfs flow would serve to store sediment above the flows of the remainder of the peak, thus limiting sand transport farther downstream and helping to conserve sandbars. The variability in flows within the peak would also serve to water higher-elevation vegetation.

Low base flows would be provided from July through January. These low flows would provide for warmer water temperatures, especially in years when releases are warm, and would also serve to reduce overall sand transport during the remainder of the year.

Under Alternative F, the only adjustment to base operations would be sediment-triggered HFEs implemented according to the HFE protocol (Reclamation 2011b) for the entire LTEMP period. There would be no mechanical removal of trout or TMFs. However, the rapid drop from peak flow to base at the end of June could incidentally serve much the same function as a TMF, thus acting to reduce the overall high trout production rates expected under a steady flow regime.

Other than testing the effectiveness of HFEs as implemented under the HFE protocol, there would be no explicit experimental or condition-dependent triggered actions under Alternative F. As with other alternatives, an ongoing monitoring program would be used to determine the response of resources to operations, and adjustments to those operations would be made consistent with adaptive management.

2.2.7 Alternative G

The objective of Alternative G is to maximize the conservation of sediment, in order to maintain and increase sandbar size. The alternative is based on the hypothetical best-case scenario suggested by Wright, Schmidt et al. (2008) for conservation of sand inputs from tributaries downstream of Glen Canyon Dam. Under Alternative G, flows would be delivered in a steady pattern throughout the year with no monthly differences in flow other than those needed to adjust operations in response to changes in forecast and other operating requirements such as equalization (Tables 2-1 and 2-13; Figure 2-29). In an 8.23-maf year, steady flow would be approximately 11,400 cfs.

TABLE 2-12 Flow Parameters under Alternative F in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	506	0.0615	8,229	0
November	490	0.0595	8,229	0
December	506	0.0615	8,229	0
January	506	0.0615	8,229	0
February	611	0.0742	11,000	0
March	861	0.1046	14,000	0
April	1,012	0.1229	17,000	0
May	1,230	0.1494	20,000	0
June	1,190	0.1446	20,000	0
July	445	0.0540	7,229	0
August	445	0.0540	7,229	0
September	430	0.0523	7,229	0

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

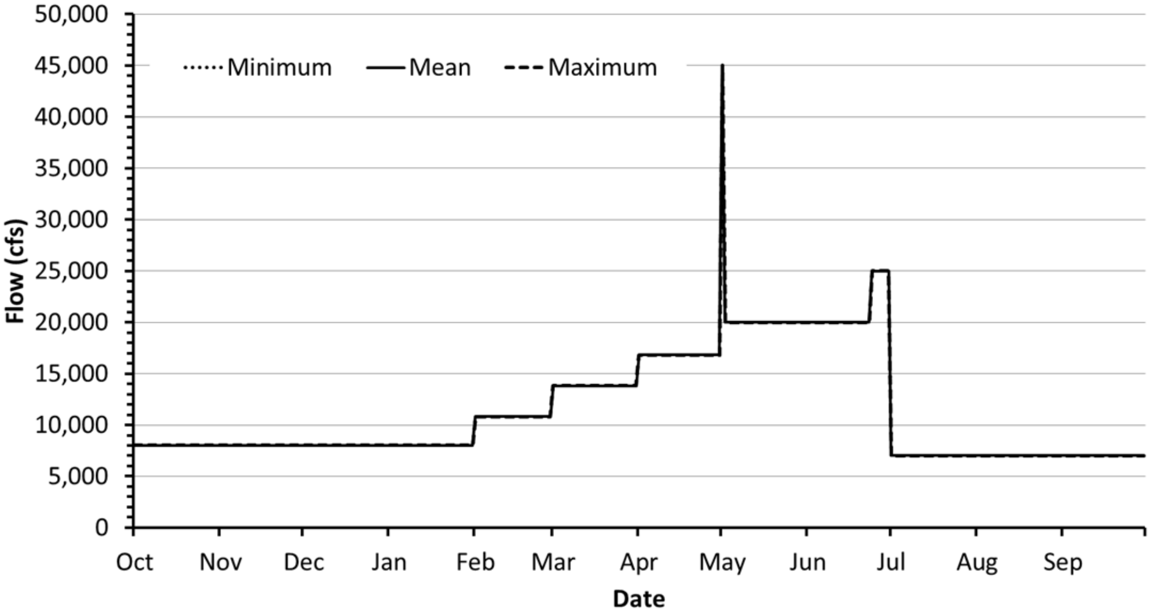

FIGURE 2-28 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative F in an 8.23-maf Year Based on the Values Presented in Table 2-12

TABLE 2-13 Flow Parameters under Alternative G in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	699	0.0849	11,368	0
November	699	0.0849	11,747	0
December	677	0.0823	11,010	0
January	699	0.0849	11,368	0
February	676	0.0821	12,172	0
March	699	0.0849	11,368	0
April	699	0.0849	11,747	0
May	631	0.0767	10,262	0
June	699	0.0849	11,747	0
July	676	0.0821	10,994	0
August	699	0.0849	11,368	0
September	677	0.0823	11,377	0

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded. Variation among months reflects adjustments based on changing forecasts.

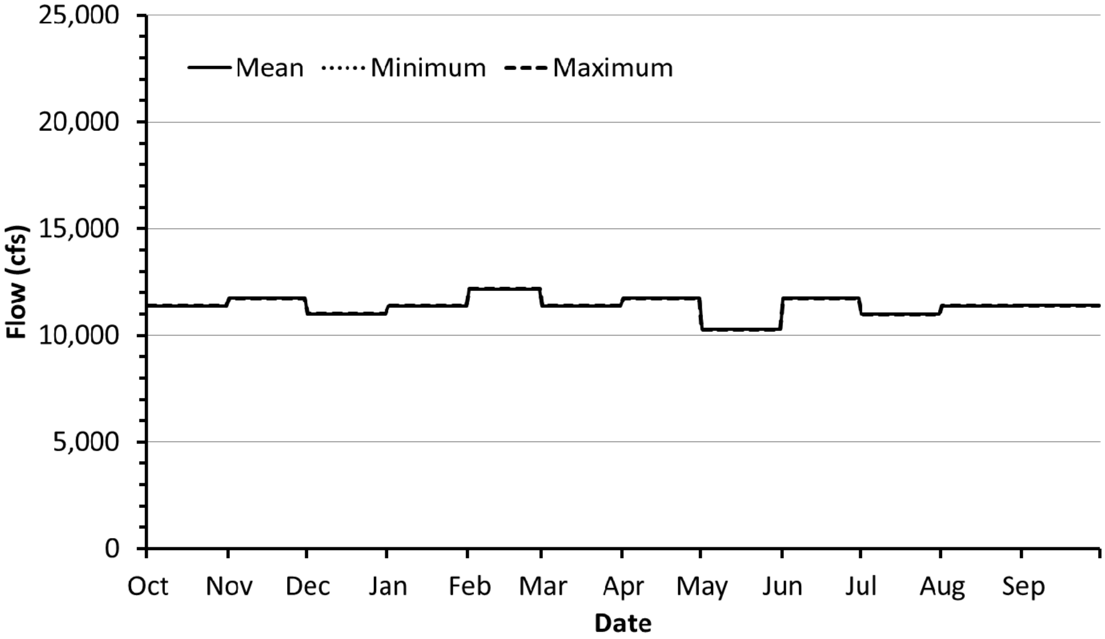

FIGURE 2-29 Mean, Minimum, and Maximum Daily Flows under Alternative G in an 8.23-maf Year Based on Values Presented in Table 2-13

Under Alternative G, spring and fall HFEs would be implemented in accordance with the HFE protocol (Reclamation 2011b), but with experimental modifications as described under the Alternative C (Section 2.3.3.2) including (1) adjustments of operations before and after HFEs occur; (2) implementing spring proactive HFEs in high-volume equalization years prior to equalization releases; and (3) implementation of longer duration (>96-hr) HFEs. Under Alternative G, however, the volume of a longer duration HFE would not be constrained by the volume of a 96-hr 45,000-cfs HFE, but instead could be as long as 336 hr (14 days), depending on the amount of sediment available for transport.

Under Alternative G, mechanical removal of trout would be implemented consistent with the Nonnative Fish Control protocol (Reclamation 2011a) in the Little Colorado River reach. Testing and implementation of TMFs as triggered by trout recruitment would occur as described for Alternative C (Section 2.3.3.3).

2.3 ALTERNATIVES CONSIDERED AND ELIMINATED FROM DETAILED STUDY

During the scoping and analysis periods for the LTEMP DEIS, a number of alternative concepts were either (1) developed and explored by the DOI's LTEMP team; (2) developed as complete alternative proposals by the Cooperating Agencies or other stakeholders; or (3) suggested by the public as alternatives that should be included in the LTEMP DEIS. Four of the alternative concepts developed by the DOI's LTEMP team are described in Section 2.2 (Alternatives C, D, F, and G). Also described in Section 2.2 are two complete alternative proposals submitted by stakeholders. Alternative E was submitted by the Basin States and Alternative B was submitted by CREDA, a non-profit association of energy customers of the Colorado River Storage Project, in response to the DOI's request to all stakeholders for alternative concepts. Other alternatives are identified below with an explanation of why they were not included as an alternative in the EIS.

2.3.1 Modified Low Fluctuating Flows with Extended Protocols

The DOI's LTEMP team identified an alternative that would be comparable to Alternative A, but that would extend the existing HFE and Nonnative Fish Control protocols past their current expiration date of 2020 through the entire LTEMP period. This alternative was in part identified to enable a more direct comparison of impacts with the remaining alternatives that would extend the protocols through the LTEMP period. Alternative A, by definition, would only implement existing decisions up to their expiration dates. Preliminary analyses indicated that this alternative would perform similarly to Alternative A, especially for hydropower generation value (based on monthly release volumes and daily flow fluctuations), and would be similar to Alternative E with respect to humpback chub, trout, and sediment resources (because of alternative-specific flow fluctuations and the frequency of HFEs). The analysis of the seven alternatives evaluated in the EIS evaluates a reasonable range of possible operational and experimental variations, including those of this alternative, without requiring additional detailed analysis for NEPA compliance purposes.

2.3.2 Naturally Patterned Flow Alternative

A Naturally Patterned Flow Alternative, similar to the Historic Pattern Alternative, described in the 1995 EIS (Reclamation 1995), was identified by the DOI's LTEMP team as a possible alternative early in the LTEMP EIS process. Under this alternative, flows would vary from month to month in conformance with the historic flow pattern and would not include daily fluctuations. HFEs would be sediment triggered, but their timing would be shifted to conform to natural flood timing. Minimum flows could be lower than the current minimum, and maximum flows as high as full bypass, scaled for the annual hydrologic condition. Transitions between months would be relatively smooth, with established limitations on the rate of change between days.

Preliminary modeling indicated that sand transport under this alternative, as originally defined, would be far higher than under other alternatives. When originally conceived, this alternative featured sediment augmentation as a critical element. Without sediment augmentation (see rationale for not including sediment augmentation or other new infrastructures in alternatives in Section 2.4.1), estimated sand transport would be too great to sustain downstream sediment resources, and, as a consequence, this alternative was considered to not meet the purpose, need, and objectives of the LTEMP. High rates of erosion were also identified for the Historic Pattern Alternative in the 1995 EIS (Reclamation 1995), and were considered as the primary reason for eliminating it from further consideration. It should be noted that Alternative F was developed by the DOI in response to the findings of the preliminary analysis of the Naturally Patterned Flow Alternative, and was included in the EIS to provide an alternative that achieved the original objectives of the Naturally Patterned Flow Alternative while reducing overall sediment transport, and thus, meeting the purpose, need, and objectives of the LTEMP.

2.3.3 Seasonal Fluctuations with Low Summer Flow Alternative

The Seasonal Fluctuations with Low Summer Flow Alternative would feature low summer (July through September) flows each year, and was developed by the DOI's LTEMP team to provide warmer water temperatures for native fish and other aquatic resources. Excess water volume not released in the summer would be released in the winter (December through February) and late spring (May and June). Fluctuations would be low in the summer (2,000 cfs daily range), but would conform to MLFF-level fluctuations the remainder of the year. The alternative would use the existing HFE and Nonnative Fish Control protocols for the entire LTEMP period. Preliminary analyses for this alternative were completed, but it was not included as an LTEMP alternative because the analyses suggested that the alternative did not perform better than others with regard to impacts on native fish populations and other aquatic resources. This is largely a consequence of the marginal gains in temperature (about 1 or 2°C at the Little Colorado River confluence) that are expected to occur under low flows. Since the alternative did not meet its intended objectives, there was no compelling reason to include it as an alternative in the EIS. Other alternatives, such as Alternatives C, D, and E, were determined to provide benefits to native fish and aquatic resources, and therefore met the objectives of the Seasonal Fluctuations with Low Summer Flow Alternative.

2.3.4 Grand Canyon First! Alternative

A "Grand Canyon First!" Alternative was proposed as an alternative concept in a number of public scoping comments. In this alternative, consideration of the ecology and wildlife of Grand Canyon would be the paramount consideration, restoring Grand Canyon to its historical state to the extent possible. This alternative would recognize the Grand Canyon Protection Act (GCPA) as the primary source to inform the LTEMP EIS, and the operations of Glen Canyon Dam should help to preserve the natural and cultural resources of Grand Canyon. Public comment provided objectives but not an operational regime, non-flow actions, or experimental plan to achieve those objectives; therefore, this alternative was not sufficiently well-defined to include as an LTEMP alternative. Although this concept was not included as an alternative in the EIS, all LTEMP alternatives include many of the concepts that are in this proposal; for example, operations to achieve sediment and native fish objectives are included in LTEMP alternatives, including Alternatives C, D, E, F, and G.

2.3.5 Species Community and Habitat-Based Alternative

Several members of the public suggested that a Species Community and Habitat-Based Alternative be included in the LTEMP DEIS. This proposed alternative concept was intended to contribute to the conservation or recovery of endangered or extirpated species, such as the humpback chub, razorback sucker, southwestern willow flycatcher (*Empidonax traillii extimus*), and Kanab ambersnail. It would also contribute to the conservation of other non-listed aquatic and riparian species (including flannelmouth sucker [*Catostomus latipinnis*], bluehead sucker [*Catostomus discobolus*], and speckled dace [*Rhinichthys osculus*]) to reduce the need to list them under the ESA. This would include an ESA Recovery Implementation Program focused on supporting native species communities that ensures that their habitat-based needs are met. This alternative would include a management program for the trout at Lees Ferry that also provides for protection of humpback chub and other native fish populations downriver, and a quality recreational fishery at Lees Ferry. Public comment provided objectives, but not an operational regime, non-flow actions, or experimental plans to achieve those goals, and, therefore, was not sufficiently well-defined to include as an LTEMP alternative. Although this concept was not included as an alternative in the EIS, other elements of the concept, such as operations to achieve sediment, native fish, and trout management objectives, are included in several alternatives, including Alternatives B, C, D, E, F, and G. Each of these LTEMP alternatives identifies operations to protect existing ecological resources.

2.3.6 Stewardship Alternative

During public scoping, commenters suggested consideration of a Stewardship Alternative that utilized a flow regime that would best serve Grand Canyon and be aligned with the GCPA, with no consideration given to hydropower. Commenters provided objectives but not an operational regime, non-flow actions, or experimental plan to achieve those objectives, and, therefore, this alternative was not sufficiently well-defined to include as an LTEMP alternative. In addition, the suggestion that hydropower generation should not be considered as an objective is counter to the purpose, need, and objectives of the proposed action. Although this concept was not included as an alternative in the EIS, all LTEMP alternatives include many concepts in this proposal; for example, operations to achieve sediment and native fish objectives are included in several LTEMP alternatives, including Alternatives C, D, E, F, and G. Each of these LTEMP alternatives places high priority on protecting downstream resources and identifies flow and non-flow actions to protect those resources.

2.3.7 Twelve-Year Experiment of Two Steady-Flow Alternatives

Grand Canyon Trust proposed a 12-year series of three 4-year experimental blocks. Operations during the first 4-year period would be seasonally adjusted steady flows. Operations during the next 4-year block would be MLFF. The final 4-year block would feature year-round steady flows. All three flow regimes would include high-flow releases under sediment-enriched conditions. After 12 years, the three regimes would be analyzed to determine which had the most favorable results consistent with the GCPA.

This alternative was not included in the EIS, because the proposed experimental design would most likely lead to confounding of effects by the hydrologic patterns that occurred during the LTEMP period, differences in annual volumes, the potential need for equalization operations during one or more years, and differences in sediment supply between treatments. These confounding factors would make it difficult to interpret the results of the proposed experiment. The three operational regimes proposed for this alternative were, however, included as separate alternatives.

2.3.8 Decommission Glen Canyon Dam Alternative

During the public scoping period, several members of the public suggested that an alternative that would result in the decommissioning of Glen Canyon Dam should be considered. Comments suggested that the dam could be either left in place or removed. If left in place, reservoir levels would be equalized to upstream inflows. Lake Powell water levels would drop, and the sediments would begin to cut new banks and form a new channel that would flow around and through the dam. Public comments advocating the decommissioning of the dam mentioned the benefits of opening currently submerged areas to new recreational activities; restoring the environmental, recreational, and cultural resources of the Grand Canyon and the Colorado River basin to their pre-dam conditions; and positively affecting the health of the Colorado River Ecosystem. One commenter suggested transferring the contents of Lake Powell and Lake Mead to underground storage locations to avoid losing water to evaporation. The commenter stated that there are abundant nearby natural underground locations that could accommodate the volume of water from 6 years of the Colorado River's annual flow.

The Decommission Glen Canyon Dam Alternative was not included in the EIS because it would not meet the purpose, need, or objectives of the proposed action. The alternative would not allow compliance with water delivery requirements, including the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other federal requirements and regulations, including the GCPA. This alternative was proposed by members of the public during scoping for the 1995 EIS on Glen Canyon Dam operations, and was not considered for detailed study for reasons similar to those presented above.

2.3.9 Fill Lake Mead First Alternative

The Fill Lake Mead First Alternative was proposed by members of the public during the public scoping comments. Under this alternative, primary water storage would shift from Lake Powell to Lake Mead, using Lake Powell as a backup for seasonal and flood control purposes. According to the commenters, there would likely be less water lost to evaporation and seepage, and there would be greater flexibility for implementing Grand Canyon restoration strategies. This alternative was not included in the EIS because it would not meet the purpose, need, or objectives of the proposed action. The alternative would not allow compliance with water release requirements, including, but not limited to, the division and apportionment of the use of the waters of the Colorado River system under the Colorado River Compact, as well as other portions of the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b). In addition, the alternative would not comply with other federal requirements and regulations, including the GCPA.

2.3.10 Full-Powerplant Capacity Operations Alternative

During the public scoping period, members of the public suggested inclusion of an alternative that allowed for full powerplant capacity operations. Commenters suggested that pre-1996 ROD operations be considered as one alternative to allow for a better understanding of the effects of MLFF operations. The Full-Powerplant Capacity Operations Alternative was not included in the EIS because it would not meet the purpose, need, and objectives of the LTEMP, including compliance with the GCPA. Although the Full-Powerplant Capacity Operations Alternative was not considered as a separate alternative in the EIS, Alternative B described in Section 2.3.2 and analyzed in Chapter 4 includes a test of "hydropower improvement flows" that would feature wide daily fluctuations (up to 20,000 cfs in some years and months).

2.3.11 Run-of-the-River Alternative

Some members of the public suggested that Glen Canyon Dam could be re-engineered to operate as a modified run-of-the-river facility. A Run-of-the-River Alternative would restore natural water and sediment flows to the greatest extent possible by reconnecting old river bypass tunnels or constructing new tunnels to bypass Glen Canyon Dam. This alternative would utilize elements of the "Fill Lake Mead First" alternative above. This alternative was not included in the EIS because it would not meet the purpose, need, or objectives of the proposed action. The alternative would not allow compliance with water delivery requirements, including the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other federal requirements and regulations, including the GCPA.

2.4 ALTERNATIVE ELEMENTS ELIMINATED FROM DETAILED STUDY

A number of elements were considered by the DOI's LTEMP team for inclusion in LTEMP alternatives, including those identified by the public during the scoping process and alternative workshop in April 2012. Many are included in the alternatives described in Section 2.2. Those eliminated from detailed study are described in this section.

2.4.1 New Infrastructure

Several infrastructure additions and modifications were initially discussed by the DOI during alternative development, including (1) sediment augmentation, (2) a TCD, (3) retrofitting of the bypass tubes to install power generation, and (4) re-engineering of the spillways if needed to allow for more frequent use. Prior to initiation of LTEMP alternative development, options for sediment augmentation, bypass generation, and a TCD were evaluated by Reclamation from engineering assessment and cost perspectives. Several of these options were described in Randle et al. (2006), Reclamation (1999b), and Vermeyen (2008).

In addition to infrastructure additions or modifications considered by the DOI, the Basin States and CREDA included several infrastructure considerations in the alternatives they proposed. These are described in the following paragraphs.

Under Alternative E, the Basin States proposed an investigation to determine the feasibility of using a pump-back system in the Paria River drainage to increase turbidity in the mainstem. This feasibility study would evaluate options, limitations, and cost-benefit. The study would investigate the possibility of installing a pumping system at Lees Ferry to transport a small amount of water up into the Paria River drainage to increase turbidity for a few weeks in the mainstem to disadvantage rainbow trout.

For Alternative B, CREDA proposed utilizing bubblers in the Glen Canyon forebay to break down the temperature differential between the surface and deeper waters and consequently provide warmer water near the turbine intakes for release downstream. To increase turbidity downstream of the dam, CREDA proposed installing one or more small check dams in the Paria River that would be used to trap sediment for release during a time when young humpback chub are entering the mainstem from the Little Colorado River, thereby enhancing their survival chances by reducing trout predation.

The DOI considers any infrastructure modifications or additions to be outside the scope of the LTEMP EIS because they are currently economically infeasible and would require additional congressional authorizations. However, the DOI does not rule out future new infrastructure if resource conditions warrant. Any infrastructure addition or modification would require additional time and study. Future potential infrastructure modifications would need to be evaluated in NEPA assessments (EAs or EISs) that fully considered the environmental impacts of construction and operation. These assessments and the construction of the infrastructure would necessarily result in some delay from the time of the LTEMP ROD and actual start of operation of the infrastructure. It could take as many as 10 years or more to evaluate and construct a TCD or sediment augmentation.

2.4.2 Flow and Non-Flow Actions

A number of flow and non-flow actions were considered by the DOI or proposed by the Cooperating Agencies, stakeholders, or the public for inclusion in the LTEMP DEIS. For various reasons, as described below, these actions were not evaluated in any of the LTEMP alternatives.

For Alternative E, the Basin States proposed that after every three store-and-release fall HFEs, the next triggered fall HFE would be a “rapid response” HFE in which Glen Canyon Dam releases would be increased within hours or days of a significant input of sediment from the Paria River. Under the alternative, more than one rapid response HFE could occur within a given fall period in response to multiple inputs of sediment. Rapid-response HFEs were not considered in the EIS because of implementation concerns, including the difficulty in coordinating releases with tributary inputs, insufficient lead time to fully notify the public and other stakeholders, and potential safety concerns associated with insufficient notification.

For Alternative B, CREDA proposed including several experiments that were not included in the alternative as analyzed. These included ponding flows and fluctuating flow experiments. Ponding flows are those relatively high flows that produce low-velocity areas in tributary mouths for the benefit of humpback chub. However, there is little evidence that ponding flows would provide benefit to YOY humpback chub; therefore, ponding flows were not included as an experimental element in Alternative B or any other alternative. Power production experiments would be short-term flow experiments intended to investigate alternative fluctuating flow parameters that might be compatible with downstream resource objectives. Because specific details of these experiments were not provided by CREDA, they were not included as an experimental element in Alternative B as evaluated in the LTEMP EIS.

Some members of the public suggested that the equalization flows identified in the Interim Guidelines (Reclamation 2007a) be released in ways that minimize impacts and provide benefits. Adverse impacts of 2011 equalization flows on sediment resources were mentioned by several commenters. It was suggested that alternatives should consider adjusting timing and magnitude of equalization flows to coincide with available sediment from the Paria and Little Colorado Rivers to help rebuild beaches in the Grand Canyon. It was also suggested that equalization flow releases should be implemented over several years rather than in a single year, as currently implemented under the 2007 ROD. This suggested adjustment to an existing recent decision would not meet the purpose, need, or objectives of the LTEMP, which requires compliance with existing, laws, regulations, and decisions.

Members of the public suggested considering introducing variability in flows by including ≥45,000-cfs flows. It was suggested that flows of 60,000 cfs and more would be beneficial for sediment-dependent resources in the Grand Canyon. This alternative element was not considered for inclusion in alternatives because it would require use of the dam’s spillway, which was designed for occasional use in cases of high inflow and dam safety. The spillway is not engineered for repeated use during normal operations, and any modifications to the dam's infrastructure are considered outside the scope of the EIS, as discussed in Section 2.4.1. In addition, the spillways can only be used when the reservoir levels are very high; it is not possible to use the spillways at low reservoir elevations. It should be noted that, over the course of the LTEMP period, it is possible that such very high flows would occur as a result of normal hydrologic variation, as happened in the very wet years of 1983 and 1984.

Mechanical removal of trout in the Glen Canyon reach was considered initially by the DOI during the development of Alternative C. This alternative element was not included in the EIS because modeling indicated that the effort necessary to effect a reduction in the Glen Canyon trout population with electrofishing would be expensive, impractical, and largely ineffective. TMFs, as included in several LTEMP alternatives, were considered a much more practical way of managing trout population size in the Glen Canyon reach.

2.5 SUMMARY COMPARISON OF ALTERNATIVES

The analysis of alternatives used both quantitative and qualitative approaches (see Section 4.1). As described in Section 2.1, a structured decision analysis approach was used to help develop alternatives and to provide a basis for assessing the performance of alternatives. For this latter function, performance metrics for various resource goals were developed by subject matter experts in Reclamation, NPS, GCMRC, Argonne, FWS, and WAPA, with input from other Cooperating Agencies, AMWG stakeholders, and Tribes (see Appendices B and C). The structured decision analysis approach was not the only method by which the alternatives were analyzed, and a preferred alternative was identified. The identification of a preferred alternative was based on the full EIS analysis and considerations relating to qualitative and quantitative evaluations of impacts. Public comment, socioeconomic considerations, AMWG stakeholder input, and other factors were also considered in this decision.

For those metrics that could be quantitatively assessed with mathematical models that estimated the response of resources to environmental conditions, a full range of potential hydrologic conditions and sediment conditions were evaluated for a 20-year period (water years 2013–2033) that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell inflow scenarios for the 20-year LTEMP were sampled from the 105-yr historic record (water years 1906–2010). This method produced 21 separate hydrology traces (sequence of monthly and annual water volumes) for analysis that represented a range of possible conditions from dry to wet. In addition to these 21 hydrology traces, three 20-year sequences of sediment input from the Paria River sediment record (water years 1964–2013) were analyzed that represented low, medium, and high sediment input. In combination, the 21 hydrology traces and three sediment traces resulted in an analysis that considered 63 possible hydrology-sediment scenarios for analysis.

Mathematical models were used to predict resource metric values for each of the alternatives under the 63 hydrology-sediment combinations. For resource impacts that could not be modeled, a qualitative approach that relied on observed effects of flows and other factors on resources, as published in the scientific literature, was used to assess impacts. See Chapter 4 for a description of the modeling and assessment approaches used for each resource topic.

After this modeling of Alternative D was completed, several adjustments were made to specific operational and experimental characteristics based on discussions with the Cooperating Agencies and stakeholders. These adjustments included (1) an increase in release volume in August with corresponding decreases in May and June (in an 8.23-maf year, the increase was 50 kaf in August, i.e., from 750 to 800 kaf; and a reduction of 25 kaf each in May and June; these changes were applied proportionally to monthly volumes in drier and wetter years); (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE; and (4) a prohibition on sediment-triggered spring HFEs in the same water year as an extended-duration (>96 hr) fall HFE. Adjustments made to Alternative D after the DEIS was published, and based on comments received from stakeholders on the DEIS, included (1) elimination of load-following curtailment after a fall HFE and (2) a prohibition on proactive spring HFEs in the same water year as an extended-duration fall HFE. As described in Section 4.1 of the EIS, for most resources other than sediment and hydropower, these adjustments to Alternative D are expected to result in little if any change in impacts relative to those predicted for the earlier modeled version of Alternative D. In addition, for all resources but hydropower, the relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments.

Table 2-14 presents a summary of impacts anticipated under each alternative by resource topic. For resources where the effects of the adjustments to Alternative D mentioned in the previous paragraph could be noticeable (i.e., sediment and hydropower), the effects are identified in footnotes to Table 2-14. More detailed information on the impacts of alternatives is provided in Chapter 4.

TABLE 2-14 Summary of Impacts of LTEMP Alternatives on Resources

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Water (hydrology and water quality)	No change from current condition in reservoir elevations, annual operating tiers, monthly release volumes, mean daily flows, or mean daily changes in flow (up to 8,000 cfs). No change in temperature or other water quality indicators.	Compared to Alternative A, no change from current condition related to reservoir elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months (up to 12,000 cfs). Hydropower improvement flows would cause even greater mean daily flow changes. Negligible differences in temperature or other water quality indicators.	Compared to Alternative A, some change from current condition related to reservoir elevations (<2 ft difference for each reservoir at end of Dec.), annual operating tiers (2.1% of years), monthly release volumes and mean daily flows (lower in Aug. and Sept.); lower mean daily changes in flow in all months (up to 6,200 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.2-ft difference for Lake Powell, no difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months (up to 8,000 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.3-ft difference for Lake Powell, 0.1-ft difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows (lower in Aug. and Sept.); higher mean daily changes in flow in all but Sept. and Oct. (up to 9,600 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (about a 3-ft difference for each reservoir at the end of Dec.) and annual operating tiers (2.1% of years); large changes in monthly release volumes and mean daily flows (high volume in May and June, low in other months); steady flows throughout the year. Greatest summer water temperature and increased potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.4-ft difference for Lake Powell, 1.4-ft difference for Lake Mead at end of Dec.) and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year. Some increase in summer water temperature and potential for bacteria and pathogens.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Sediment	Least HFEs of any alternative would result in lowest potential for building sandbars (highest impact of alternatives), highest sand mass balance (lowest impact of alternatives.	Compared to Alternative A, sandbar building potential would increase 10%, but higher fluctuations would result in lower sand mass balance (80% decrease).	Compared to Alternative A, sandbar building potential would increase 157%, but sand mass balance would decrease 112%.	Compared to Alternative A, sandbar building potential would increase 152%, but sand mass balance would decrease 47%.[b]	Compared to Alternative A, sandbar building potential would increase 119%, but sand mass balance would decrease 96%.	Compared to Alternative A, sandbar building potential would increase 167%, but sand mass balance would decrease 230% (highest impact of alternatives).	Compared to Alternative A, sandbar building potential would increase 176%; lowest impact of alternatives), but sand mass balance would decrease 182%.
Natural processes	Existing natural processes related to flow, water temperature, water quality, and sediment resources would continue, but replenishment of sandbars would diminish after 2020 when HFEs would cease.	Compared to Alternative A, most natural processes would be unchanged, but there would be less nearshore habitat stability as a result of greater within-day fluctuations.	Compared to Alternative A, there would be more nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer and fall water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be comparable nearshore habitat stability as a result of similar within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be lower nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within season variability; more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, year-round steady flows would result in the greatest nearshore habitat stability, slightly higher summer water temperatures, and the highest potential of any alternative to build sandbars and retain sand in the system.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Aquatic ecology	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Compared to Alternative A, slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows; habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced; lower trout abundance; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; habitat quality and stability for nonnative and native fish may be higher; higher trout abundance even with implementation of TMFs and mechanical removal; no difference in humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; experimental macroinvertebrate production flows (only featured in this alternative) may further increase productivity and diversity; habitat quality and stability for nonnative and native fish are expected to be slightly higher; negligible change in trout abundance with implementation of TMFs, and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base, and similar or increased drift; habitat quality and stability for nonnative and native fish would be slightly lower; lower trout abundance with implementation of TMFs and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year; positive effects on nonnative and native fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives; higher trout abundance; slightly lower humpback chub abundance.	Compared to Alternative A, relatively high productivity of aquatic food base and long-term drift; greater habitat stability for nonnative and native fish; higher trout abundance even with implementation of TMFs and mechanical removal; slightly lower humpback chub abundance.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Vegetation	Overall index = 3.66 reflecting an adverse impact relative to current condition resulting from: narrowing of Old High Water Zone; an expected decrease in New High Water Zone native plant community cover, decrease in native diversity, increase in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Compared to Alternative A, a 6% increase in overall index reflecting an improvement in vegetation conditions (but a decline under hydropower improvement flows); impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, an increase in arrowweed, an increase in native diversity (decrease under hydropower improvement flows), an increase in native/nonnative ratio (decrease under hydropower improvement flows), and a decrease in wetland community cover.	Compared to Alternative A, a 13% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone; decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover.	Compared to Alternative A, an 8% increase in overall index reflecting an improvement in vegetation conditions; impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, an increase in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover. Lowest impact of alternatives.	Compared to Alternative A, a 3% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, an increase in arrowweed, and a decrease in wetland community cover.	Compared to Alternative A, a 14% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative), a decrease in arrowweed, and a decrease in wetland community cover. Highest impact of alternatives.	Compared to Alternative A, a 7% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; less nearshore habitat stability would result in decreased production of aquatic insects and would adversely impact species that eat insects or use nearshore areas, especially with the implementation of hydropower improvement flows; less decline of wetland habitat; however, hydropower improvement flows would cause a greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; least decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; increased production of aquatic insects due to more even monthly volumes could benefit species that eat insects or use nearshore areas, but benefits may be offset by higher within-day flow fluctuations.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greatest decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects (highest among alternatives) and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Cultural resources	No change from current conditions regarding the slumping of terraces in Glen Canyon during HFEs (Glen Canyon flow effects index [GFEI] = 22.7); availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (wind transport of sediment index [WTSI] = 0.16); stability of Spencer Steamboat; and visitor time off river (time off river index [TORI] = 0.82).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (1.5% increase in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (7.5% increase in WTSI); no change in the stability of Spencer Steamboat or visitor time off river. Experimental hydropower improvement flows would increase the potential for slumping compared to Alternative A (1.6% increase in GFEI and a decrease in the availability of windblown sand (−9.5% decrease in WTSI).	Compared to Alternative A, a decrease in the potential for slumping of terraces in Glen Canyon (4.4% decrease in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (137% increase in WTSI); negligible effect on stability of Spencer Steamboat or visitor time off river (<1% change in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (3.1% increase in GFEI), an increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (139% increase in WTSI); negligible effect on stability of Spencer Steamboat; a decrease in visitor time off river (1.6% increase in TORI).	Compared to Alternative A, a decrease in the potential for slumping of terraces in Glen Canyon (6.4% decrease in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (96% increase in WTSI); negligible effect on stability of Spencer Steamboat; a decrease in visitor time off river (1.9% increase in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon due to sustained high flows in the spring (62% increase in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (88% increase in WTSI); negligible effect on stability of Spencer Steamboat; an increase in visitor time off river (8.9% decrease in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (8.7% increase in GFEI), an increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (193% increase in WTSI); negligible effect on the stability of Spencer Steamboat; a decrease in visitor time off river (2.1% increase in TORI).

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal resources	Operations would result in no change in the amount of sand available for wind transport to cultural resource sites; a negligible loss of riparian diversity; a small loss of wetlands and no impact on Tribal water and economic resources. No TMFs, but mechanical trout removal could be triggered. After 2020, potential adverse impact on culturally important archaeological sites.	Compared to Alternative A, operations would result in a slight increase in the amount of sand available for wind transport to cultural resource sites except during hydropower improvement flows, when there would be a slight decrease. There would be a slight loss in riparian diversity and slightly more loss in wetlands. There would be no impact on Tribal water and economic resources. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the second largest loss in wetlands and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the least amount of wetlands loss across alternatives; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could occur with or without triggers. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.[c]	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; an increase in wetlands loss; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites but would result in an increase in the potential for river runners to explore and potentially damage places of cultural importance during May and June. The greatest loss of wetlands, largest increase in invasive species, and lowest riparian plan diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs	Compared to Alternative A, operations would result in the greatest potential increase in the amount of sand available for wind transport to cultural resource sites; the third-largest wetlands loss across alternatives; and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal resources (Cont.)						or mechanical trout removal. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	
Recreation, visitor use, and experience	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, few lost day-rafting visitor days (49 over 20-year period), and declining camping area.	Compared to Alternative A, a comparable number of HFEs and higher fluctuations result in more lost day-rafting visitor days (45% increase) in Glen Canyon, highest number of large trout (13% increase), lowest trout catch rates, most navigability concerns, and similar camping area (5% increase in index).	Compared to Alternative A, more HFEs and lower fluctuations result in more lost day-rafting visitor days in Glen Canyon (543% increase), similar number of large trout (3% decrease), higher trout catch rates; fewer navigation concerns, and more camping area (170% increase in index).	Compared to Alternative A, more HFEs and comparable fluctuations result in more lost day-rafting visitor days in Glen Canyon (610% increase), similar number of large trout (5% increase), similar trout catch rates, similar navigation concerns, and more camping area (158% increase in index).	Compared to Alternative A, more HFEs, higher fluctuations, and more frequent flows below 8,000 cfs result in more lost day-rafting visitor days in Glen Canyon (261% increase), more large trout (8% increase), lower trout catch rates, more navigation concerns, and more camping area (118% increase in index).	Compared to Alternative A and all other alternatives, frequent HFEs, steady flows, and lack of trout management actions result in most lost day-rafting visitor days in Glen Canyon (1,776% increase), higher trout catch rates, but fewest large trout (22% decrease); very few navigability concerns, and more camping area (191% increase in index).	Compared to Alternative A, more HFEs and steady flows result in few additional lost day-rafting visitor days in Glen Canyon (4% increase), higher trout catch rates, but fewer large trout (9% decrease); very few navigability concerns, and greatest potential increase in camping area (220% increase in index).

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Wilderness	No change from current conditions. Declining camping area following cessation of HFEs would reduce opportunity for solitude; intermediate effects on crowding at rapids and levels of fluctuations; lowest disturbance from experimental actions.	Compared to Alternative A, similar decline in camping area, somewhat more crowding at rapids, greatest level of fluctuations, greater disturbance from non-flow actions, especially under experimental hydropower improvement flows.	Compared to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, similar crowding at rapids, similar level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, less crowding at rapids, no fluctuations, greater disturbance from non-flow actions, but no mechanical removal of trout.	Compared to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Visual resources	No change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Glen Canyon Dam hydropower economic and retail rate impacts	No change from current condition. Second-highest firm capacity and sixth-lowest total cost to meet electric demand over the 20-year LTEMP period. No change in average electric retail rate or average monthly residential electricity bill.	Compared to Alternative A, a 0.3% decrease in average daily generation (MWh) and a 3.8% increase in firm capacity (MW); a 0.02% decrease in the cost of generation, a 0.45% decrease in the cost of capacity, and a 0.04% decrease in total cost to meet electric demand over the 20-year LTEMP period; a small decrease in the average electric retail rate (−0.27%) and the average monthly residential electricity bill (−$0.27) in the year of maximum rate impact.	Compared to Alternative A, a 0.8% decrease in average daily generation (MWh) and a 17.5% decrease in firm capacity (MW); a 0.08% increase in the cost of generation, a 6.09% increase in the cost of capacity, and a 0.41% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.43%) and average monthly residential electricity bill ($0.40) in the year of maximum rate impact.[d]	Compared to Alternative A, a 1.1% decrease in average daily generation (MWh) and a 6.7% decrease in firm capacity (MW); a 0.12% increase in the cost of generation, a 3.12% increase in the cost of capacity, and a 0.29% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.39%) and average monthly residential electricity bill ($0.38) in the year of maximum rate impact.[e]	Compared to Alternative A, a 0.7% decrease in average daily generation (MWh) and a 12.2% decrease in firm capacity (MW); a 0.06% increase in the cost of generation, a 3.52% increase in the cost of capacity, and a 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.50%) and average monthly residential electricity bill ($0.47) in the year of maximum rate impact.[f]	Compared to Alternative A, a 1.9% decrease in average daily generation (MWh) and a 42.6% decrease in firm capacity (MW) (lowest of alternatives); a 0.42% increase in the cost of generation, a 4.03% increase in the cost of capacity, and a 1.17% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period; highest increase in average retail electric rate (1.21%) and average monthly residential electricity bill ($1.02) in the year of maximum rate impact.	Compared to Alternative A, a 1.7% decrease in average daily generation (MWh) and a 24.2% decrease in firm capacity (MW); a 0.34% increase in the cost of generation, a 7.39% increase in the cost of capacity, and a 0.73% increase in total cost to meet electric demand over 20-year LTEMP period; a small increase in average retail electric rate (0.64%) and average monthly residential electricity bill ($0.59) in the year of maximum rate impact.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Hoover Dam hydropower economic impacts	No change in the value of generation.	Compared to Alternative A, no change in the value of generation.	Compared to Alternative A, a 2.0% increase in the value of generation.	Compared to Alternative A, a 1.0% increase in the value of generation.	Compared to Alternative A, a 1.2% increase in the value of generation.	Compared to Alternative A, a 4.1% increase in the value of generation.	Compared to Alternative A, a 1.4% increase in the value of generation.
Socioeconomics	No change from current conditions in use values or economic activity, with no change in reservoir levels or river conditions. Lowest non-use value of alternatives.	Compared to Alternative A, no change in use values and economic activity associated with Lake Powell recreation, and declines in use values (up to 5.2%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Minimal decrease in use values (<0.1%), and no change in economic activity associated with Lake Mead recreation. Minimal increase in economic activity	Compared to Alternative A, declines (0.7%) in use values and economic activity (0.6%) associated with Lake Powell recreation, and in use values (up to 11.5%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 11.7%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity	Compared to Alternative A, declines in use values (0.5%) and economic activity (0.5%) associated with Lake Powell recreation, and in use values (up to 14.0%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from	Compared to Alternative A, declines in use values (1.1%) and economic activity (1.1%) associated with Lake Powell recreation, and in use values (up to 8.9%) associated with most forms of river recreation. An increase in use values (0.5%) associated with Upper and Lower Grand Canyon private boating. A decrease in economic activity for angling, with declines during HFEs. Increases in use values (0.5%) and economic activity (0.5%) associated with	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 13.2%) associated with most forms of river recreation. An increase in use values (0.3%) associated with Lower Grand Canyon private boating. A decrease in economic activity for angling, with declines during HFEs. Increases

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Socioeconomics (Cont.)		(<0.1%) from lower residential electric bills compared to Alternative A. Annual increase in non-use value of $1,511 million at the national level.	minimal decrease in economic activity from higher residential electric bills (< 0.1%). Annual increase in non-use value of $3,985 million at the national level.	expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Highest non-use value of alternatives. Annual increase in non-use value of $4,486 million at the national level.	capacity expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $3,963 million at the national level.	Lake Mead recreation. Increased economic activity from capacity expansion (up to 9.3%), and minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $2,353 million at the national level.	in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $3,524 million at the national level.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Environmental justice	No change from current conditions. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and <1 year, respectively, of LTEMP period; financial impacts related to electricity sales similar to those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 6 years and 0–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 8 years and 2–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and 0–2 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	No impact; TMFs and mechanical removal not allowed under this alternative; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers and would be greater (as much as $3.26/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	Highest impact of all alternatives; TMFs and mechanical removal triggered in 11 years and 3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Air quality	No change from current conditions in air quality or visibility.	Compared to Alternative A, a negligible increase (0.01%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.01%) in SO_2 emissions and no change in NO_x emissions; no change in visibility.	Compared to Alternative A, no change in SO_2 emissions and negligible increase in NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible increase (<0.005%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.04%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.03%) in SO_2 and negligible increase in NO_x emissions; no change in visibility.
Climate change	No change from current conditions.	Compared to Alternative A, a 0.011% increase in GHG emissions.	Compared to Alternative A, a 0.033% increase in GHG emissions.	Compared to Alternative A, a 0.042% increase in GHG emissions.	Compared to Alternative A, a 0.030% increase in GHG emissions.	Compared to Alternative A, a 0.081% increase in GHG emissions.	Compared to Alternative A, a 0.074% increase in GHG emissions.
Cumulative impacts	Contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.	Compared to Alternative A, similar sandbar building, lower trout numbers, slightly higher humpback chub numbers, greater value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly lower humpback chub numbers, lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly higher humpback chub numbers, and slightly lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, similar trout numbers, and slightly lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, much higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.

Footnotes on next page.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G

[a] The quantitative results presented here are from modeling conducted prior to making several adjustments to Alternative D, including prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE, elimination of experimental load-following curtailment after fall HFEs, and an adjustment in the monthly release volumes such that releases in August would be 50 kaf higher (800 kaf instead of 750 kaf) and releases in May and June would each be 25 kaf lower. The actual number of HFEs would be about 19.8 (1.3 fewer). As described in Section 4.1 of the EIS, for most resources, these adjustments to Alternative D are expected to result in little if any change in impacts relative to those predicted for the earlier modeled version of Alternative D. In addition, for all resources but hydropower, the relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments. Potentially noticeable effects are identified for sediment and hydropower in footnotes (b) and (e).

[b] Impacts on sediment presented for Alternative D in this table were based on modeling performed prior to making several adjustments to the alternative (see footnote [a]). The actual number of HFEs would be lower and would result in a slightly lower sand load index (SLI) and higher sand mass balance index (SMBI). Change in monthly release volumes would result in a slight increase in sediment transport (1.2%), resulting in a lower SLI and a lower SMBI. Elimination of load-following curtailment would result in a 0.6% decrease in SMBI. The relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments. See Section 4.1 for more detail.

[c] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition (1.3 fewer), and this reduction in frequency could reduce the impacts on Hualapai docks under Alternative D.

[d] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative C compared to Alternative A, estimated at $148 million, by about $24.5 million resulting in a total cost difference of about $173 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.41% increase in cost to a 0.48% increase in cost. The relative ranking of Alternative C compared to other alternatives would not change as a result of adding the cost of experimental low summer flows.

[e] Impacts on hydropower resources presented for Alternative D in this table were based on modeling performed prior to making several adjustments to the alternative (see footnote [a]), and they do not include the cost of experimental low summer flows. Experimental low summer flows would increase costs by $15 million, while the adjustments would reduce costs by $58.9 million. Combined, the cumulative effect of these adjustments may reduce the relative cost of Alternative D compared to Alternative A, estimated at $104 million, by approximately $44 million over a 20-year period; the resulting difference from Alternative A would be $60 million. These adjustments reduce the percent difference relative to Alternative A from a 0.29% increase in cost to a 0.17% increase in cost. These adjustments would also result in slight reductions to the retail rate costs. The relative ranking of Alternative D compared to other alternatives would change from fourth to third lowest cost. See Section 4.13.3.4 for more detail.

[f] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative E compared to Alternative A, estimated at $91 million, by about $9.95 million resulting in a total cost difference of about $101 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.25% increase in cost to a 0.28% increase in cost. The relative ranking of Alternative E compared to other alternatives would change from third to fourth lowest cost.

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3 AFFECTED ENVIRONMENT

Chapter 3 describes the environmental resources (physical, biological, cultural, recreational, and socioeconomic) that could be affected by the range of alternatives for implementing the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP), as described in Chapters 1 and 2. The extent to which each specific resource may be affected by each alternative is discussed in Chapter 4, Environmental Consequences.[1]

3.1 PROJECT AREA

The project area includes the area potentially affected by implementation of the LTEMP (including normal management and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead (Figure 3.1-1). More specifically, the scope primarily encompasses the Colorado River Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (GCNP). It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. This section of the river runs through Glen, Marble, and Grand Canyons in Coconino and Mohave Counties in northwestern Arizona.

Although this EIS focuses primarily on the Colorado River Ecosystem, the affected area varies by resources and extends outside of the immediate river corridor for some resources and cumulative impacts. Portions of Glen Canyon National Recreation Area (GCNRA), GCNP, and Lake Mead National Recreation Area (LMNRA) outside the Colorado River Ecosystem are also included in the affected region for certain resources due to the potential effects of LTEMP operations. For resources such as socioeconomics, air quality, and hydropower, the affected region was larger and included areas potentially affected by indirect impacts of the LTEMP.

3.1.1 Colorado River Setting

The Colorado River rises in the Rocky Mountains of Colorado, flows southwesterly about 1,450 mi, and terminates in the Gulf of California. Its drainage area of 242,000 mi^2 in the United States represents one-fifteenth of the area of the country. As presented in the Colorado River Basin Water Supply and Demand Study (Reclamation 2012h), almost 40 million people in the seven western states of Arizona, California, and Nevada (Lower Division States), and

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[1] Pre-dam conditions are discussed in this chapter to provide historical context on certain resources that exist in an already altered environment; however, such references are not intended to form the basis for comparison of the alternatives in this Environmental Impact Statement (EIS), or to provide goals for achieving resource conditions. The action alternatives are compared to the No Action Alternative (Alternative A), as is the standard practice for National Environmental Policy Act of 1969 as amended (NEPA), compliance.

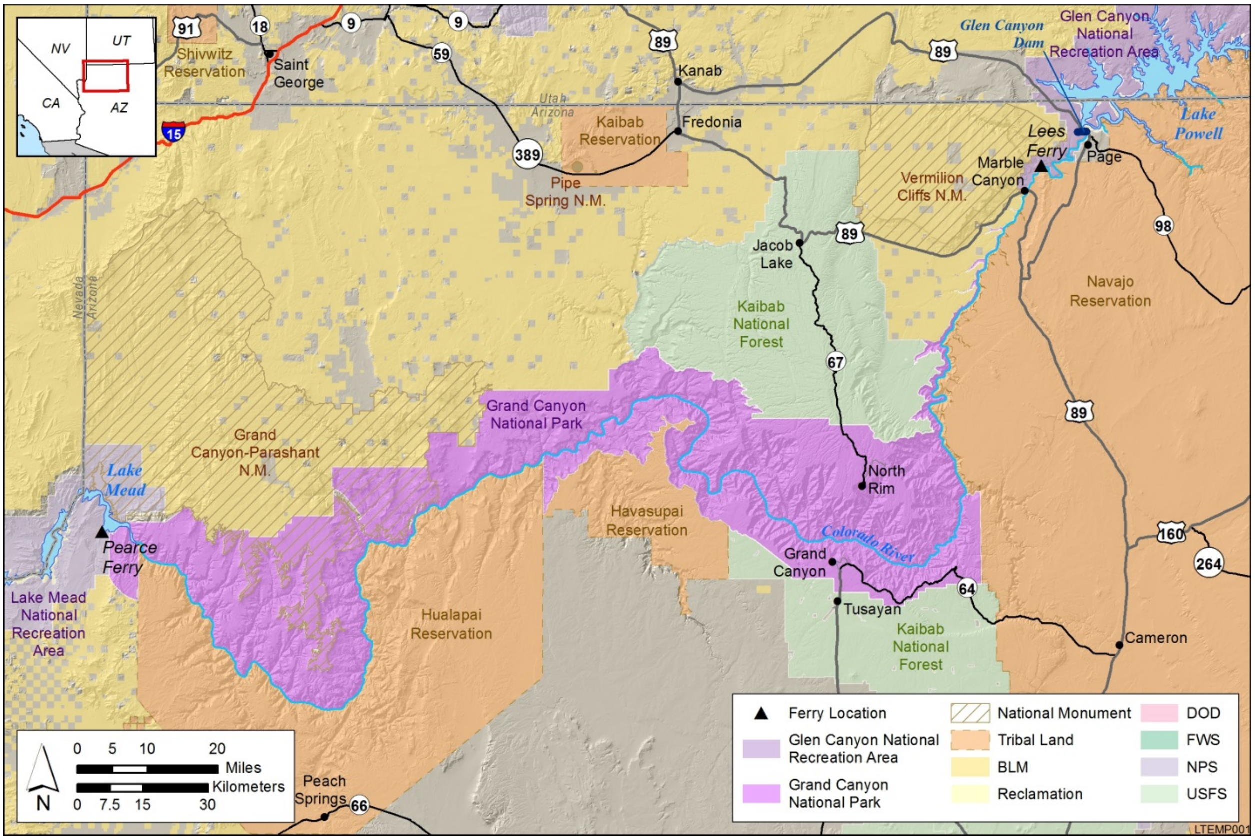

FIGURE 3.1-1 LTEMP Project Area and Surrounding Lands (This map is for illustrative purposes, not for jurisdictional determinations; potential area of effects varies by resource as described in this chapter and in Chapter 4.)

Colorado, New Mexico, Utah, and Wyoming (Upper Division States) rely on the Colorado River and its tributaries to provide some or all of their municipal water needs. Colorado River water is used to irrigate nearly 5.5 million ac of land in the Basin, which produces about 15% of the nation's crops and about 13% of its livestock. The Colorado River is the lifeblood for at least 22 federally recognized American Indian Tribes , 7 National Wildlife Refuges, 4 National Recreation Areas, and 11 National Parks.

Hydropower facilities along the Colorado River supply more than 4,200 megawatts (MW) of electrical capacity to help meet the power needs of the West and reduce the use of fossil fuels (Reclamation 2012h). The primary units of the Colorado River Storage Project (CRSP)—Glen Canyon, Flaming Gorge, Blue Mesa, Morrow Point, and Crystal—provide the majority of the hydroelectric power for the Upper Basin. CRSP has a combined installed capacity of more than 1,800 MW, with Glen Canyon accounting for approximately 73% of the CRSP facilities' total generating capacity.

Given the many and varied uses that depend on Colorado River water, as well as the significant public interest in the region, it is important yet difficult to achieve a suitable balance in the use of the Colorado River. Out of the 1,450-mi length of the Colorado River, it is the

284-mi reach that flows through Glen Canyon Dam and the Grand Canyon that is the affected reach under discussion in this EIS. It is against this background that the resources of the Colorado River Ecosystem are discussed and evaluated.

3.1.2 Geologic Setting

For more than 5 million years, the forces of geologic uplift, weathering, and downcutting of the Colorado River and its tributaries have carved the Grand Canyon. The canyon is about a mile deep and varies in width from a few hundred feet at river level to as much as 18 mi at the rim. The erosive forces of the river cut only a narrow gorge; other geologic forces, including flowing water over the canyon walls, freezing and thawing temperatures, and abrasion of rock against rock cut the wider canyon. The Colorado River acts like a huge conveyor belt transporting finer sediment particles to the ocean.

In cutting the canyon, the river has exposed rocks of all geologic eras, covering a span of nearly 2 billion years. The rocks of the Grand Canyon are part of the Colorado Plateau, a 130,000-mi^2 area covering most of the Colorado River Basin. The elevation of the canyon rim varies between about 5,000 and 8,000 ft above mean sea level (AMSL), with the North Rim being about 1,000 ft higher than the South Rim.

Glen Canyon cuts through the massive Navajo Sandstone of the Mesozoic Era and is about 200 million years old. Downstream from Lees Ferry, a sequence of nearly horizontal sedimentary rocks of the Paleozoic Era appears at river level, beginning with the Kaibab Formation that caps much of the canyon rim. In Marble Canyon, the river passes through cavernous Redwall Limestone. The river is narrower here and in other places where the Paleozoic rocks are relatively hard, but becomes wider through the more easily eroded formations. The shelves of Tapeats Sandstone (more than 500 million years old) at the base of the Paleozoics appear near the mouth of the Little Colorado River. Farther downstream, the narrowest reaches are cut through the dense, dark-colored Vishnu Schist of the Proterozoic era (about 1.7 billion years old). In the Toroweap area, the youngest rocks in the canyon are exposed, which are remnants of lava flows that poured over the North Rim about 1 million years ago during the Cenozoic era. The hardened lava still clings to the canyon walls, and basalt boulders still affect river flow at Lava Falls Rapid. The Grand Wash Cliffs mark the southwestern edge of the Colorado Plateau and the mouth of the Grand Canyon at the headwaters of Lake Mead.

3.1.2.1 Tribal Perspectives on Geologic Setting[2]

The Colorado River, through the Glen Canyon, Marble Canyon, and Grand Canyon (Canyons), has a prominent place in the traditional cosmology of the Havasupai Tribe, Hopi

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[2] Sections in this EIS entitled "Tribal Perspectives" are intended to represent the viewpoints of the Tribes who participated as Cooperating Agencies based on their input. The text was provided by the Tribes, and only minor typographic modifications were made prior to insertion into the EIS.

Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and the Southern Paiute Tribes and continues to have an important place in their contemporary cultures and economies. For example, Navajo oral history concerning the Grand Canyon and its tributaries states that it was developed during the time of creation of this world. Water was everywhere, and the world was named Ni′ Hodisq—the Glittering World. The people were given this world to live in after a series of trials with the native inhabitants (Chiishta Dootl′ izh, Chiishta Litso, and Chiishta Ligaii). The people discussed ways to make the world habitable; after much talk, they decided that rivers, creeks, and streams would be created to drain the world, which in turn would become the veins of the earth. The Colorado River is one of those veins. Haashch′ eeh yalt′ i′ i, the Talking God, and Haasch′ eehoghaan, the Evening God, became the advisors to the people, and under their direction, the world was created as it is today. In other oral histories, people say that Ghaa′ ask′idii, the Humpback God, created the Grand Canyon. After this world was given to humans by the Holy People, they cleared the water away. The Humpback God stood in the center of the world and dragged his cane from east to west and created the canyon. The water drained and created the rivers, creeks, and streams, which became the veins of the earth. The essence of the Humpback God is manifested by bighorn sheep and mountain goats as seen in the Grand Canyon today (Roberts et al. 1995).

3.1.3 Climatic Setting

Climatic conditions in the area vary considerably with elevation. At Bright Angel Campground (elevation 2,400 ft) near Phantom Ranch, the climate is characterized by mild winters, hot summers, and low rainfall. Average high temperatures range from about 15°C (59°F) in winter to 39°C (103°F) in summer. Low temperatures range from about 4 to 24°C (39 to 76°F). Average annual precipitation, mostly in the form of rain, is about 11.2 in.

In contrast, the climate at the North Rim (elevation 7,800 to 8,800 ft) is characterized by cold winters, cool summers, and abundant precipitation with snowfall. Average high temperatures range from 4°C (39°F) in winter to 24°C (75°F) in summer; low temperatures range from about –8 to 6°C (18 to 43°F). Average annual precipitation is 33.6 in. The South Rim (elevation 7,000 ft) receives about 16 in. of precipitation annually. Average high temperatures range from 5°C (41°F) in winter to 29°C (84°F) in summer; average low temperatures range from –8°C (18°F) in winter to 12°C (54°F) in summer.

The Upper Colorado River Basin (drainage basin above Lee Ferry[3]) is generally classified as semiarid and the Lower Basin (drainage basin below Lee Ferry) as arid. The climate varies from cold-humid at the headwaters in the high mountains of Colorado, New Mexico, Utah, and Wyoming, to dry-temperate in the northern areas below the mountains, and arid in the lower southern areas. Annual precipitation in the higher mountains occurs mostly as snow, which

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[3] "Lee" Ferry is the reference point that marks the division between the Upper and Lower Colorado River basins. The point is located in the mainstream of the Colorado River 1 mi below the mouth of the Paria River in Arizona. "Lees" Ferry is the historic location of Colorado River ferry crossings (1873 to 1928) and the current site of the U.S. Geological Survey (USGS) stream gage above the Paria River confluence.

results in as much as 60 in. of precipitation per year. Thousands of square miles in the lower part of the basin are sparsely vegetated because of low rainfall and poor soil conditions. Rainfall in this area averages from 6 to 8 in., mostly from cloudburst storms during the late summer and early fall.

3.1.4 Glen Canyon Dam Releases and Flow

The major function of Glen Canyon Dam (and Lake Powell) is water storage to support a multitude of uses. In this EIS, river flows below the dam are referred to as releases or flows. River flow is measured in cubic feet per second (cfs). Annual and monthly volumes are measured in acre-feet (ac-ft). The amount of water and its pattern of release directly or indirectly affect physical, biological, cultural, and recreational resources within the Colorado River Ecosystem.

Hydropower generated from Glen Canyon Dam is cleaner in terms of air emissions, and its generation is more flexible and more responsive than many other forms of electrical generation. As such, the Glen Canyon Powerplant is an important component of the electrical power system of the western United States. The powerplant has eight generating units with a maximum combined capacity (i.e., the maximum electric output of the eight generating units) of 1,320 MW. When possible, higher releases are scheduled in high-demand winter and summer months to generate electricity when demand is greatest.

Water releases from Glen Canyon Dam fluctuate on a daily and hourly basis to maximize the value of generated power by providing peaking power during high-demand periods. More power is produced by releasing more water through the dam’s generators. Daily releases can range from 5,000 to 31,500 cfs, but actual daily fluctuations have been constrained to less than this maximum range as a result of implementing the 1996 Record of Decision (ROD) (Reclamation 1996). These constrained fluctuations result in a downstream “fluctuation zone” between low and high river stages (i.e., the water level associated with a given flow) that is inundated and exposed on a daily basis.

Glen Canyon Dam also affects downstream water temperature and clarity. Historically, the Colorado River and its larger tributaries were characterized by heavy sediment loads, variable water temperatures, large seasonal flow fluctuations, extreme turbulence, and a wide range of dissolved solids concentrations. The dam has altered these characteristics in the Colorado River between Glen Canyon Dam and Lake Mead. Before the dam, water temperature varied on a seasonal basis from highs around 27°C (80°F) to lows near freezing. Now, water released from Glen Canyon Dam averages 9°C (48°F) year round, although release temperatures vary depending on the water level in Lake Powell and other factors, and water temperature warms by about 1°C (1.8°F) for every 30 mi traveled downstream during warmer months of the year (Reclamation 1999b). Lake Powell traps sediment that historically was transported downstream. The dam releases clear water, and the river becomes muddy when downstream tributaries contribute sediment, as during summer monsoon storms.

3.1.5 Colorado River Ecosystem Resource Linkages

The Colorado River Ecosystem formed in a sediment-laden, seasonally flooded environment. Virtually all of the Colorado River Ecosystem resources are associated with or dependent upon water and sediment. Interactions among water volume and releases patterns, sediment transport, and downstream resources support a complex ecosystem. The construction of Glen Canyon Dam altered the natural dynamics of the Colorado River. It is understood that Glen Canyon Dam collects and stores water for beneficial purposes and in the process traps sediment and associated nutrients that previously traveled down the Colorado River. The regulated releases from Glen Canyon Dam and Lake Powell have resulted in an altered aquatic and terrestrial ecosystem compared to that which existed before Glen Canyon Dam.

This EIS is focused on potential changes to current operations at Glen Canyon Dam, the impacts they may have on Colorado River Ecosystem resources, water management and hydropower generation, and the determination of whether such changes can further improve resource conditions in the Colorado River Ecosystem. Specifically, the question is whether the alternative actions and experiments identified in this EIS can lead to changes in the current Modified Low Fluctuating Flow (MLFF) operation in a manner that improves resource conditions in the Colorado River Ecosystem consistent with existing laws.

The following discussion addresses the current resources of the affected environment and how dam operations affect them either directly or through linkages among resources.

3.2 WATER RESOURCES

This section presents information about the water resources of the affected area, including Lake Powell, the Colorado River and portions of its tributaries below Glen Canyon Dam, and Lake Mead (especially the inflow area of the reservoir). Information is organized within the broad topics of hydrology and water quality and includes information on the operation of Glen Canyon Dam and current conditions in these topical areas.

The hydrology of the Colorado River, as discussed in this EIS, refers to the water volumes, flow rates, and open channel hydraulics (i.e., characteristics of the conveyed flow such as depths and velocities) of the reservoirs, the river, and its tributaries. These aspects of Colorado River hydrology are directly affected by the proposed action of changes in operations at Glen Canyon Dam. Hydrology directly affects water quality variables in the downstream river environment such as temperature, salinity, and turbidity. Sediment transport and channel and floodplain morphology (e.g., pools, rapids, sandbars, and terraces) are controlled and shaped by the river's hydrologic properties.

From a human needs perspective, the construction and operation of Glen Canyon Dam, in addition to other dams in the basin, allow the distribution of Colorado River water as envisioned by the Colorado River Compact and the related Law of the River. These dams also provide the opportunity to deliver water to the farms, ranches, and communities that depend on Colorado River water.

From an ecosystem and habitat perspective, dam operations define and can change the Colorado River Ecosystem attributes that support aquatic and terrestrial species and communities. This EIS examines whether current operations at Glen Canyon Dam can be modified in a manner, consistent with existing law, to protect and improve these resources as contemplated in the Grand Canyon Protection Act of 1992 (GCPA).

From a recreational perspective, the dam and dam operations provide both flat water and river-based recreational opportunities. Dam operations provide predictable and relatively stable flow conditions that allow a viable year-round recreational opportunity that might otherwise not have existed. Certain dam operations impact the quality of a river recreational experience, such as fewer or smaller sandbars to recreate on and fewer high flows for whitewater rafters. But, with the addition of flat water recreation on the reservoir and predictable dam operations, there are also recognizable benefits to recreation and the regional economy.

From a power generation perspective, hydropower provides a cleaner (in terms of air emissions) and flexible renewable energy source that provides peaking power to help maintain a stable power grid. In the case of Glen Canyon Dam, the major component of the CRSP, revenues from power generation provide funds for repayment of the federal investment in the CRSP facilities, the infrastructure to support existing and additional water development in the Upper Basin, as well as environmental programs such as the Upper Colorado and San Juan Recovery Implementation Programs for the four Colorado River Endangered Fish, and the Glen Canyon Adaptive Management Program.

From a Tribal perspective, the Colorado River is considered the lifeblood of ancestral Tribal lands. The Fort Mojave Tribe, Havasupai, Hopi, Hualapai, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes depend upon the Colorado River and the land it supports for water supply; economic growth; business; and historical, cultural, and spiritual connection.

3.2.1 Hydrology

The primary source for the total annual water flow in the Colorado River Basin is mountain snowmelt emanating from the Rocky Mountains in the Upper Colorado River Basin. Therefore, unregulated river flows are typically very high in the late spring and early summer and diminish rapidly by midsummer, although flows in late summer through autumn sometimes increase following monsoonal rain events (Reclamation 2007a). In general, the average annual natural flow of the Colorado River at Lees Ferry over the 105-year period (water years 1906 through 2010) has averaged around 15 million acre-feet (maf), but has ranged between approximately 5.4 and 25.4 maf (Reclamation 2007a, 2013a). The period from water years 2000 to 2010 was the driest 11-year period in the more than 100-year historical record for the Colorado River Basin (average annual flow of 12.1 maf); the period from water years 1999 to 2010 was the second-driest 12-year period (12.5 maf) on record (Holdren et al. 2012; GCMRC 2015a). Based on historical (1922–2015) Lees Ferry flow data from Grand Canyon Monitoring and Research Center (GCMRC) (2015a), the most recent 10-year period (2006–2015) was drier than 77% of all 10-year periods since 1922, and the most recent 20-year period (1996–2015) was drier than 73% of all 20-year periods since 1922. These two periods had average annual cumulative flows of 9.0 maf and 9.6 maf, respectively. Average annual natural flow is forecast to decline in the future (Seager et al. 2007; Vano et al. 2013; Reclamation 2012e).

3.2.1.1 Lake Powell Hydrology

Lake Powell, illustrated in Figure 3.2-1, along with its associated major tributaries, is the second-largest man-made reservoir on the Colorado River (Lake Mead is the largest) and the largest reservoir constructed by the Bureau of Reclamation (Reclamation) under the authority of the Colorado River Storage Project Act of 1956 (CRSPA). Lake Powell has a maximum live storage capacity of around 24.3 maf. At full pool capacity, the mean depth is approximately 165 ft, with a maximum depth of about 560 ft in the forebay area of the dam. Lake Powell provides water storage for use in meeting the compact obligations consistent with the Law of the River (Reclamation 2007a). Specifically, Lake Powell provides storage needed to assist the Upper Division States in meeting their Colorado River Compact obligations. Releases from Glen

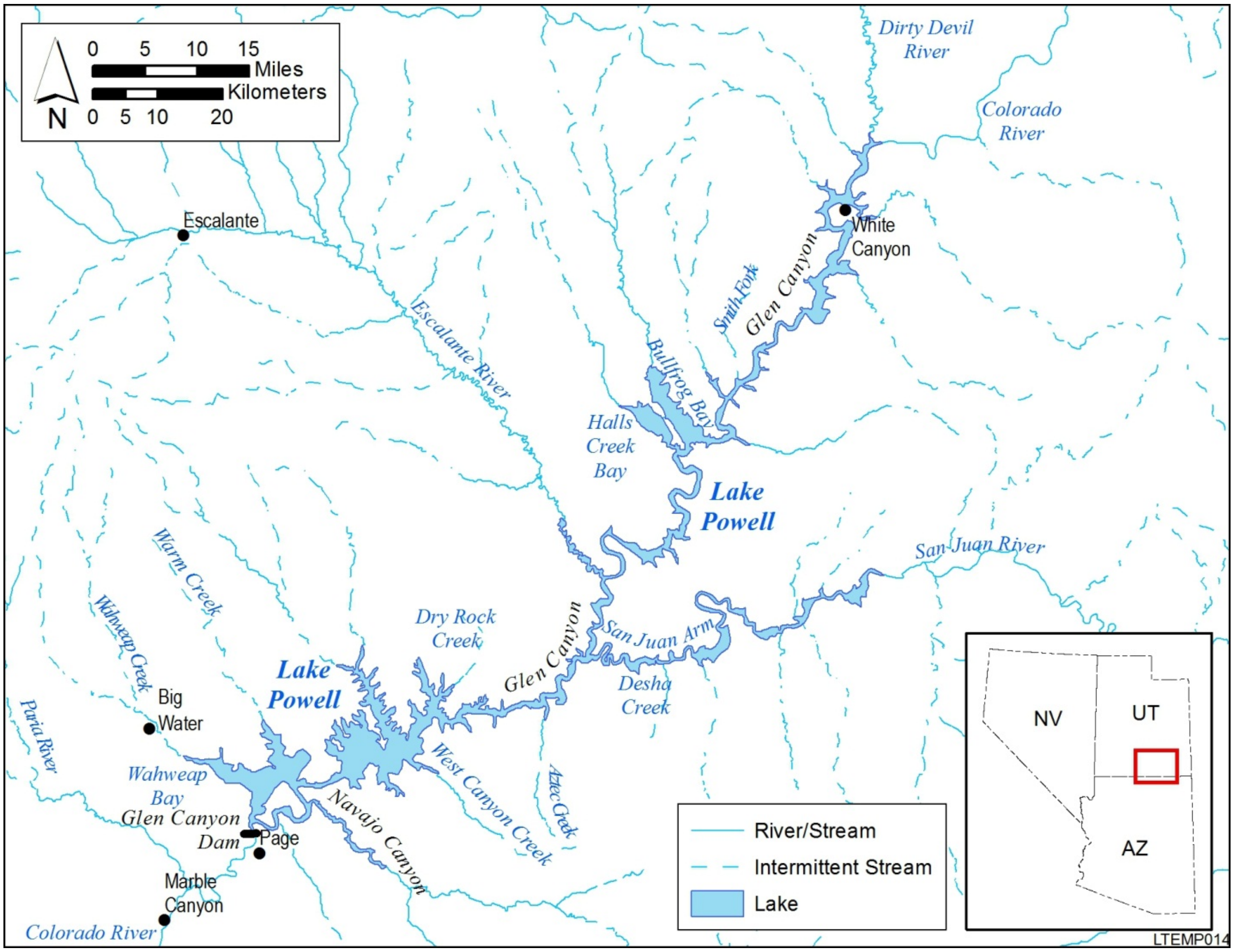

FIGURE 3.2-1 Map of Lake Powell and Associated Major Tributaries

Canyon Dam made pursuant to the Long-Range Operating Criteria (LROC), and its current implementation through the Interim Guidelines, provide the operational guidance needed to currently comply with the Colorado River Compact and related Law of the River. Water released from Lake Powell for compliance with the provisions of the Colorado River Compact also generates hydroelectric power through the Glen Canyon Dam powerplant and provides benefits to recreation. The reservoir is also used as a municipal water source for the City of Page, Navajo Community, Chapter of LeChee, and industrial water for the Navajo Generating Station.

The reservoir is long and narrow, more than 180 mi long and often less than a mile wide at the surface. Glen Canyon Dam is designed to operate between the outlet works intakes at elevation 3,370 ft AMSL and the top of the live storage pool at elevation 3,700 ft AMSL. Hydropower production would cease if Lake Powell drops below approximately 3,490 ft in elevation, or minimum power pool. As the water level changes, the surface of Lake Powell varies in size from about 52,000 ac at the top of the minimum power pool to 163,000 ac at the top of live storage, and the corresponding shoreline fluctuates from approximately 990 to 1,960 mi long. At the full pool elevation of Lake Powell, this reach includes approximately 25 mi of Cataract Canyon, more than 50 mi of the San Juan River, and approximately 170 mi of Glen Canyon (Reclamation 1995, 2007a). Almost half of the reservoir's capacity lies in its upper 100 ft, a zone where the lake overtops many local plateau surfaces. The floor of the reservoir is the incised bed of the former Colorado River, ranging from around 500 to 800 ft in width at its bottom, with a nearly uniform grade of 0.038% (Johnson and Merritt 1979). Lake Powell contains more than 90 major side canyons that have unique orientations and morphologies owing to differences in size, orientation, inflow contributions (springs and tributary flows), mixing processes, and visitor activities; however, it appears that side canyon portions of the reservoir generally have the same chemical and physical stratification as that of the main reservoir body (Taylor et al. 2004).

The hydrology of Lake Powell is primarily influenced by basin-wide hydrology and subsequently annual inflow into the reservoir. The elevation of Lake Powell and the timing, volume, and water quality of inflow into the reservoir influence the water quality of releases from Glen Canyon Dam, which has subsequent effects on the downstream water quality of the Colorado River in Glen and Grand Canyons and Lake Mead. The proposed action cannot affect Lake Powell inflow patterns.

One of the most important factors driving short-term and long-term processes in Lake Powell is the inflow hydrology, characterized by the volume and quality of inflows to the reservoir and their seasonal variation (Vernieu and Hueftle 1998). Overall, approximately 95% of the reservoir's inflow originates from the mainstream of the Colorado River and two major tributaries, the San Juan and Green Rivers (Stanford and Ward 1991; Reclamation 1995, 2007a; Wildman et al. 2011). Specifically, since water year 2005, the Upper Colorado River Basin has experienced significant year-to-year hydrologic variability. The unregulated inflow (i.e., the inflow that would occur if no upstream reservoir storage regulation existed) to Lake Powell has averaged a water year volume of 10.22 maf (94% of 30-year average for the 1981–2010 period) during the period from 2005 through 2012. The hydrologic variability during this same period (from 2005 to 2012) resulted from a low water year unregulated inflow volume of 4.91 maf

(45% of the 30-year average) in water year 2012 and a high water year unregulated inflow volume of 15.97 maf (147% of the 30-year average) in water year 2011 (Reclamation 2013c).

The majority of the inflow into Lake Powell, around 60%, occurs in late spring and early summer as a result of snowmelt in the Rocky Mountains and Upper Colorado River Basin (Iorns et al. 1965; Evans and Paulson 1983; Vernieu et al. 2005). This runoff tends to be warm, low in salinity, and turbid (i.e., sediment laden) as a result of its passage through the canyonlands and, because of its temperature, it represents the lowest-density water entering the reservoir during the year. Consequently, this water travels along the top of the reservoir as an overflow density current, leaving the waters below the penstock level (i.e., elevation 3,470 ft) essentially untouched (Johnson and Merritt 1979; Vernieu and Hueftle 1998; Vernieu et al. 2005; Reclamation 1995).

Winter inflows are cold and saline and represent the highest-density inflows to the reservoir during the year. Depending on the relative density of the existing hypolimnion (i.e., the lower layer of water in a stratified lake) in Lake Powell, winter inflows may flow along the bottom of the reservoir as an underflow-density current (Johnson and Merritt 1979), routing fresh water to the hypolimnion and displacing older oxygen-poor saline water upward toward the dam release structures. During the spring of each year from 1999 to 2008, winter inflows moving through Lake Powell had sufficient density to flow along the bottom of the reservoir (Vernieu 2010). If winter inflows are less dense than the water in the hypolimnion, as might happen following years of low runoff that establish saline conditions, they will flow into intermediate layers as an interflow-density current, eventually being discharged through the penstock outlet and leaving deeper waters stagnant (Vernieu and Hueftle 1998; Reclamation 1995; Vernieu et al. 2005). This condition was observed at Lake Powell from 1991 to 1998 (Vernieu 2010). Regardless of whether the winter inflow density current overrides or displaces the hypolimnion, there is a consistent annual pattern of colder and more saline water around the penstock withdrawal zone during the winter months.

Early dam operations were pursuant to the 1970 Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs and influenced by the Filling Criteria for Lake Powell, which were formally terminated when the reservoir filled on June 22, 1980. Operations during the relatively full period from 1980 to 1987 were controlled by the LROC, focusing on water delivery and power generation. Beginning in 1988, operations returned to the objective minimum release of 8.23 maf, as specified in the LROC. Since the early 1990s, operations have continued to focus on meeting water allocation requirements and producing power, but they were modified to address and comply with environmental values and constraints designed to minimize the effects of Glen Canyon Dam on downstream resources (Reclamation 1995). The 1996 Glen Canyon Dam ROD identified MLFF as the operating regime for Glen Canyon Dam and adopted an adaptive management framework to monitor and assess changes in operations to Glen Canyon Dam (Reclamation 1996). MLFF set monthly release ranges, minimum and maximum daily release limits, daily fluctuation limits, and ramping rates to minimize the effects of Glen Canyon Dam releases on downstream resources (Reclamation 1995). During the period following adoption of the MLFF, numerous experimental flows and non-flow actions for scientific and environmental purposes were conducted.

3.2.1.2 Hydrology of the Colorado River Downstream of Glen Canyon Dam

Annual water release volumes are established pursuant to the LROC, which is currently implemented through the Interim Guidelines for Coordinated Operations of Lake Powell and Lake Mead (Reclamation 2007a). The interim guidelines for coordinated operations of Lake Powell and Lake Mead define four operation tiers: (1) the Equalization Tier, (2) the Upper Elevation Balancing Tier, (3) the Mid-Elevation Release Tier, and (4) the Lower Elevation Balancing Tier. Releases are based upon the elevations of Lake Powell and Lake Mead as identified in Appendix D. Notably, when operating in the Equalization Tier, the Upper Elevation Balancing Tier, or the Lower Elevation Balancing Tier, scheduled water year releases from Lake Powell would be adjusted each month based on forecast inflow and projected September 30 elevations at Lakes Powell and Mead.

The annual releases since the dam was completed have included annual volumes above 8.23 maf numerous times. In general, each period of higher release was followed by a reduction in the salinity of the hypolimnion (Vernieu and Hueftle 1998). Monthly release volumes accomplish the annual releases implemented pursuant to the LROC and are based on anticipated power demands, forecasted inflows, and other factors such as storage equalization between Lake Powell and Lake Mead. High release volumes do not always coincide with peaks in reservoir inflow; instead, they coincide with times of increased power demands (e.g., January and August). Therefore, the timing of these high releases may or may not facilitate the drawing and replacement of hypolimnetic waters near the dam (Vernieu and Hueftle 1998).

The Lees Ferry gaging station (river mile [RM] 0), which has been operated by the U.S. Geological Survey (USGS) since May 1921, is approximately 15.5 mi downstream from the Glen Canyon Dam and approximately 1 mi upstream of the Paria River mouth. Its location allows a comparison of pre-dam flows with post-dam flows downstream of Glen Canyon Dam because it is located close to the dam, but is unaffected by the presence of tributary inflows. This section primarily utilizes the Lees Ferry data and analysis. Figure 3.2-2 illustrates the changes in the pattern of annual flows at Lees Ferry for the pre-dam period (from 1922, when continuous records began, through 1962) and post-dam period (1963 through 2015) (GCMRC 2015a).

The average pre-dam peak annual discharge was found to be approximately 92,000 cfs (Topping et al. 2003). The largest recorded peak flow during the pre-dam period (data record from 1921 to 1963) occurred in June 1921, soon after the installation of the Lees Ferry gage. This flood was estimated to have a peak flow of 170,000 ± 20,000 cfs; the return period of this event was estimated to be 40 years (Topping et al. 2003; O'Connor et al. 1994). The average 2-year recurrence interval flood peak was calculated from the discharge record to be 85,000 cfs (Topping et al. 2003). There is also evidence of a flood in 1884 that peaked at approximately 213,500 cfs (+ 14,500 cfs) at Lees Ferry (Topping et al. 2003). Paleoflood research has determined that during the last 4,500 years, 15 floods at Lees Ferry had peak discharges larger than 120,000 cfs. Of these floods, 10 had peak discharges greater than 140,000 to 150,000 cfs during the last 2,100 to 2,300 years, and one flood that occurred 1,200 to 1,600 years ago had a peak discharge exceeding about 300,000 cfs (Topping et al. 2003).

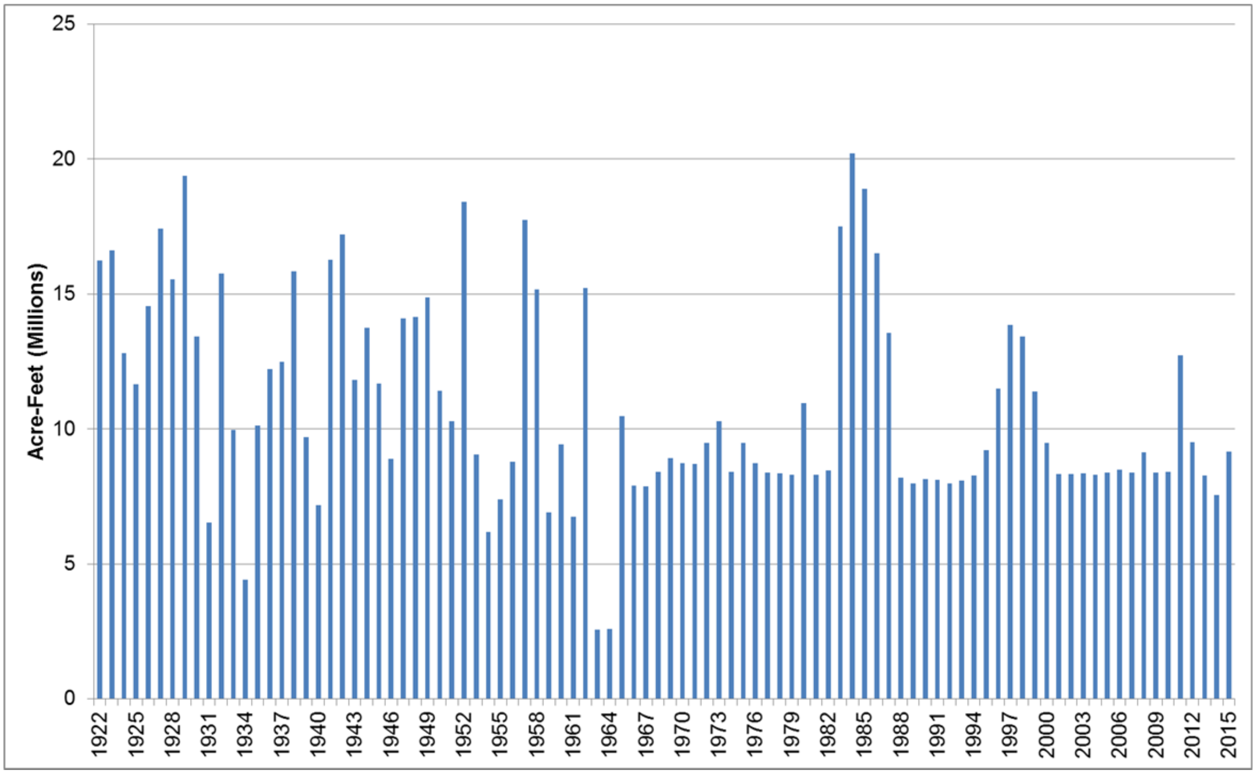

FIGURE 3.2-2 Pattern of Annual Historic Flows at Lees Ferry (Source: GCMRC 2015a)

Compared to pre-dam flows, post-dam flows exhibited a reduction in the percentage of very high flows (i.e., flows >40,000 cfs) and very low flows (flows <5,000 cfs). Post-dam monthly median flow has ranged from 10,200 cfs in October to 16,400 cfs in August (Topping et al. 2003). No post-dam months have had a median flow less than 9,000 cfs (Topping et al. 2003). The median post-dam within-day flow variation was 8,580 cfs; the within-day range exceeded 10,000 cfs on 43% of all days (Topping et al. 2003). Note that since the 1996 ROD, maximum within-day flow variation has been limited to 8,000 cfs (except during high-flow experiments [HFEs]). Within-day flow variation in releases continues downstream for the entire length of the Colorado River between Glen Canyon Dam and the headwaters of Lake Mead, but decreases as flows pass through Marble and Grand Canyons. For example, the difference between the peak and base release on October 1, 2014, was 5,470 cfs. This resulted in a difference from peak to base of approximately 3,930 cfs 13 hours later at RM 61 (just upstream of the confluence with the Little Colorado) and approximately 3,100 cfs 43 hours later at RM 225 (near Diamond Creek at the western end of Grand Canyon).

Periodic releases of relatively short duration that bypass the hydropower plant have also occurred at the Glen Canyon Dam. Recent examples of releases that have utilized the bypass outlet works or the spillways include mid-1980s flood years (using outlet works and spillways); and HFEs conducted in 1996, 2004, 2008, 2012, 2013, and 2014 (using outlet works only).

3.2.1.3 Lake Mead Hydrology

Lake Mead, illustrated in Figure 3.2-3, along with its associated major tributaries, is located approximately 30 mi east of Las Vegas, Nevada, in the Mojave Desert. It is the second of four major reservoirs on the mainstem Colorado River and was formed by the Hoover Dam, which first began impounding water in 1935 (Turner et al. 2011; Reclamation 2008a). Lake Mead has a live capacity of 26.399 maf at elevation 1,221.4 ft, and can store twice the average annual flow of the Colorado River (Reclamation 2012a). Lake Mead provides water storage to regulate the water supply and meet the water demands of the Lower Division states and Mexico consistent with the Law of the River (Reclamation 2007a). Similar to Lake Powell, its waters are also used for recreation and generation of hydroelectric power, through the Hoover Dam powerplant. Hoover Dam also provides flood control benefits. The reservoir is located within the LMNRA, which is administered by the National Park Service (NPS); however, Reclamation retains authority and discretion for the operation of both Hoover Dam and Lake Mead (Reclamation 2007a).

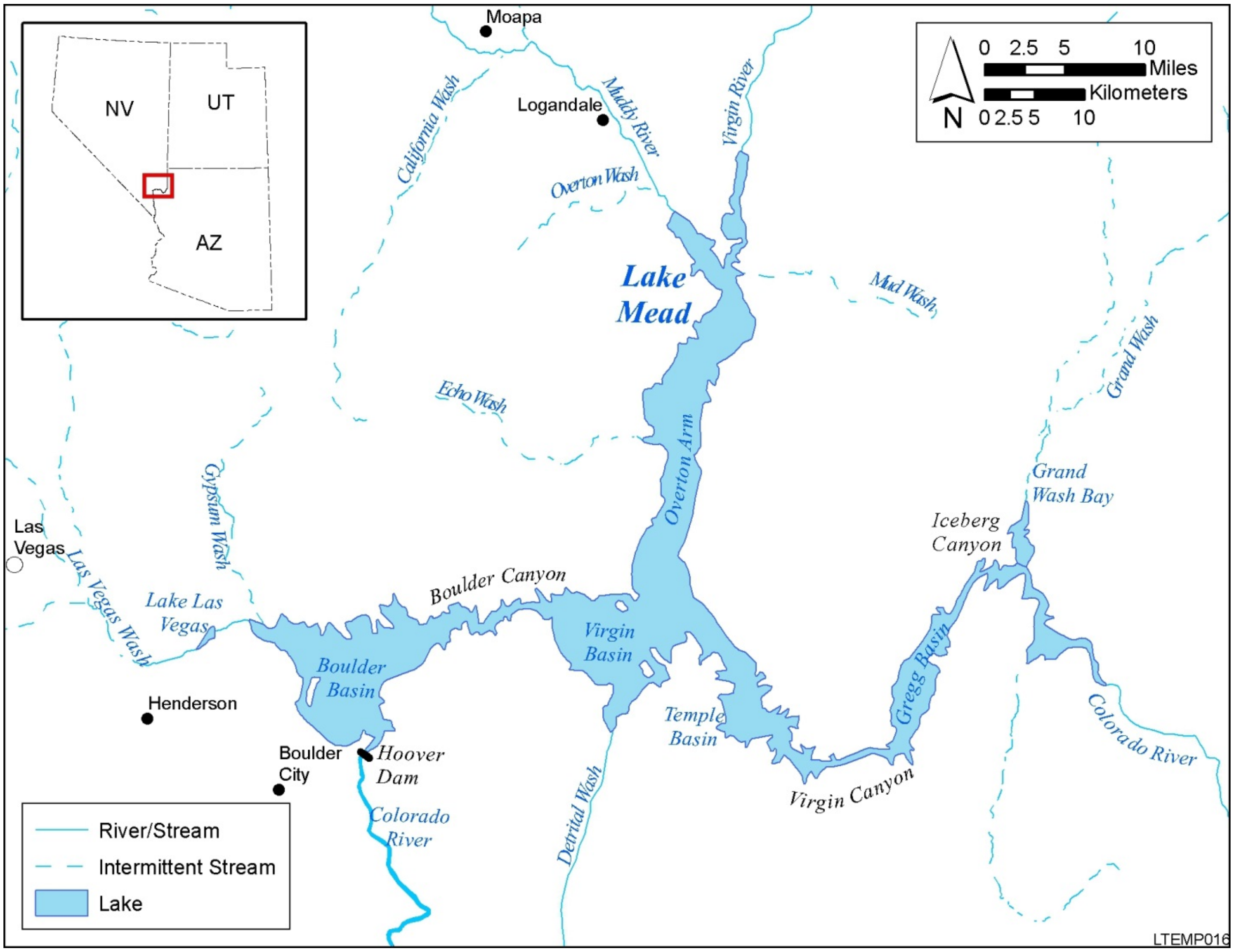

FIGURE 3.2-3 Map of Lake Mead and Associated Major Tributaries

Lake Mead is a large, deep-storage reservoir with a maximum depth of approximately 490 ft and a mean depth of nearly 170 ft. It is approximately 110 mi long, extending from the mouth of the Grand Canyon at Pearce Ferry to Hoover Dam in Black Canyon. With a width that varies from several hundred feet in the Canyons to more than 9 mi, Lake Mead has the largest surface area of any reservoir in the Northern Hemisphere, covering about 160,000 ac (250 mi^2) with a shoreline that is more than 550 mi long (Reclamation 2012a; Turner et al. 2011; Evans and Paulson 1983). The hydraulic residence time of Lake Mead depends upon reservoir release and inflow patterns (which are dependent upon Glen Canyon Dam releases). Estimates have calculated residence times on the order of about 2.6 years, based on average inflows and reservoir volumes (Turner et al. 2012; Holdren 2012). When the reservoir is thermally stratified, the epilimnion (i.e., the surface layer of water in a stratified lake) occurs from approximately 0 to 65 ft, the metalimnion (i.e., middle layer of water in a stratified lake) occurs from approximately 65 to 100 ft, and the deep hypolimnion occurs from approximately 100 ft to the bottom of the reservoir.

Lake Mead can be divided along the historical Colorado River channel into four large sub-basins: Boulder, Virgin, Temple, and Gregg; four narrow canyons: Black, Boulder, Virgin, and Iceberg; and the 30-mi-long Overton Arm, which extends from the Virgin and Muddy Rivers to the Virgin Basin (Figure 3.2-3). The Colorado River enters the eastern end of Lake Mead at the upper end of Gregg Basin.

Prior to closure of Glen Canyon Dam in 1963, Colorado River inflow into Lake Mead was unregulated and reflected natural hydrologic variability; volumes depended upon the annual snowmelt and rainfall received on the west side of the Rocky Mountains. Regulation of inflow began in 1963, when Glen Canyon Dam was constructed approximately 280 mi upstream. The formation of Lake Powell and operation of Glen Canyon Dam have altered the physical characteristics of the Colorado River inflow to Lake Mead. In general, gaged annual inflows to Lake Mead averaged about 10.9 maf between 1935 and 2001, with a pre-dam (1935–1963) value of 11.3 maf and a post-dam (1963–2001) value of 10.6 maf (Ferrari 2008). Flows decreased from 1999 through 2010 as the entire Colorado River Basin experienced drought conditions. Annual inflows to Lake Mead for the period of 1999–2010 have averaged approximately 9.0 maf, which included about 8.23 maf, with additional inflow of approximately 0.7 maf contributed by other tributaries, thus providing a total average operational inflow into Lake Mead of 9.0 maf (Holdren et al. 2012; Turner et al. 2012).

3.2.1.4 Seeps and Springs

Although the Colorado River flows through the Grand Canyon, its waters do not originate there. The Grand Canyon's only native waters (i.e., waters derived in place) come from the more than 1,000 springs and seeps that are recharged by precipitation on the high plateaus surrounding the canyon (i.e., Coconino on the South Rim and Kaibab on the North Rim) and discharged along the walls below the rim. Some springs, such as Pumpkin Spring and Fence Spring, are within the area of the Colorado River Ecosystem that is potentially affected by the proposed action.

Although springs make up less than 0.01% of the Grand Canyon's landscape, they are ecologically important (Rice 2013). Each spring is unique and supports a distinctive array of flora and fauna, many of which are endangered and endemic (i.e., found nowhere else) (NPS 2014a). It has been estimated that species diversity is 100 to 500 times greater in the vicinity of the springs than in the surrounding areas (NPS 2014a). Any changes or declines in flow of a small spring or seep may change a perennial system into an intermittent one, or dry the system out completely. Thus, species such as riparian plants, fish, amphibians, and invertebrates that rely on these water sources may be lost because they do not often have a mechanism to move across the desert landscape to a new water source (Rice 2013).

Tribal Perspectives on Seeps and Springs

Many springs and seeps also hold cultural significance for Native Americans in the region. For example, from the Zuni perspective, the earth is circular in shape and is surrounded on all sides by ocean. Under the earth is a system of covered waterways, all ultimately connecting with the surrounding oceans, springs, and lakes, which are the openings to this system (Bunzel 1932) and are regarded as sacred to the Zuni because they provide water, a life-giving substance that is necessary to maintain life within the Southwest's harsh environment. Springs are specifically "considered to be the most precious things on Earth" (Hart 1980). The Grand Canyon contains numerous springs that are utilized among all religious groups for traditional and religious practices and play an integral role in water collecting by the Zuni people for ceremonial use.

The Hualapai consider *Ha'thi-el* (Salty Spring), a sacred spring within the Canyon, to contain a petroglyph site that tells of the creation of the Hualapai and other Pai peoples (HDCR 2010). Other springs, such as Pumpkin Spring at RM 213 and Medicine Spring at the downstream end of Lava Falls Rapid, are warm mineral springs and are considered to have healing properties. Pumpkin Spring is immediately above the level of typical operational flows, although in the pre-dam past it would have regularly been inundated and flushed during the frequent flood episodes. During periods when it has not been frequently inundated and flushed, concentrations of algae, bacteria, and minerals may affect the health of the spring.

All springs in the Canyons have a spiritual importance to the Hopi; water in general is a central feature in all of Hopi philosophy, and springs in particular are considered to be altars (Hough 1906). Water is collected at a number of springs in the Canyons for ceremonial use by Hopi, and prayers are offered to all of the spring locations. The Sipapuni, the origin location for the Hopi people, is a spring. Springs provide habitat for culturally important plants and animals that are rare in the otherwise arid region. Finally, springs have a key historical importance as water sources for the Hopi ancestors who resided in the Canyons.

The Havasupai are dependent on the springs that emit from the shallow and deep aquifers on their reservation and in GCNP. The spring water that flows through the Village of Supai and over the spectacular waterfalls on the reservation delivers approximately 49,000 ac-ft per year to the Colorado River. The Havasupai consider all springs to be sacred, with some having particular significance in tribal religious and cultural practices. They have also historically farmed at the major springs, including what is now called Indian Garden in GCNP (Hirst 1985).

3.2.2 Water Quality

3.2.2.1 Lake Powell Water Quality

The stratification of Lake Powell influences many chemical and biological processes in the reservoirs and, as a result, influences the characteristics and quality of water that is released to the Colorado River below the dam (Hart and Sherman 1996). As described previously, Lake Powell is thermally and chemically stratified into density layers that differ vertically and longitudinally. In general, vertical stratification varies seasonally and is determined by the relative density of different layers of the reservoir; longitudinal variation in water quality is the result of currents moving through the reservoir (Vernieu et al. 2005). The physical, chemical, and biological characteristics of Lake Powell have a direct effect on the quality of water drawn from and released below Glen Canyon Dam.

Lake Powell is thermally stratified through much of the spring, summer, and early fall (typically April–October) (Figure 3.2-4). In general, the epilimnion of Lake Powell, which

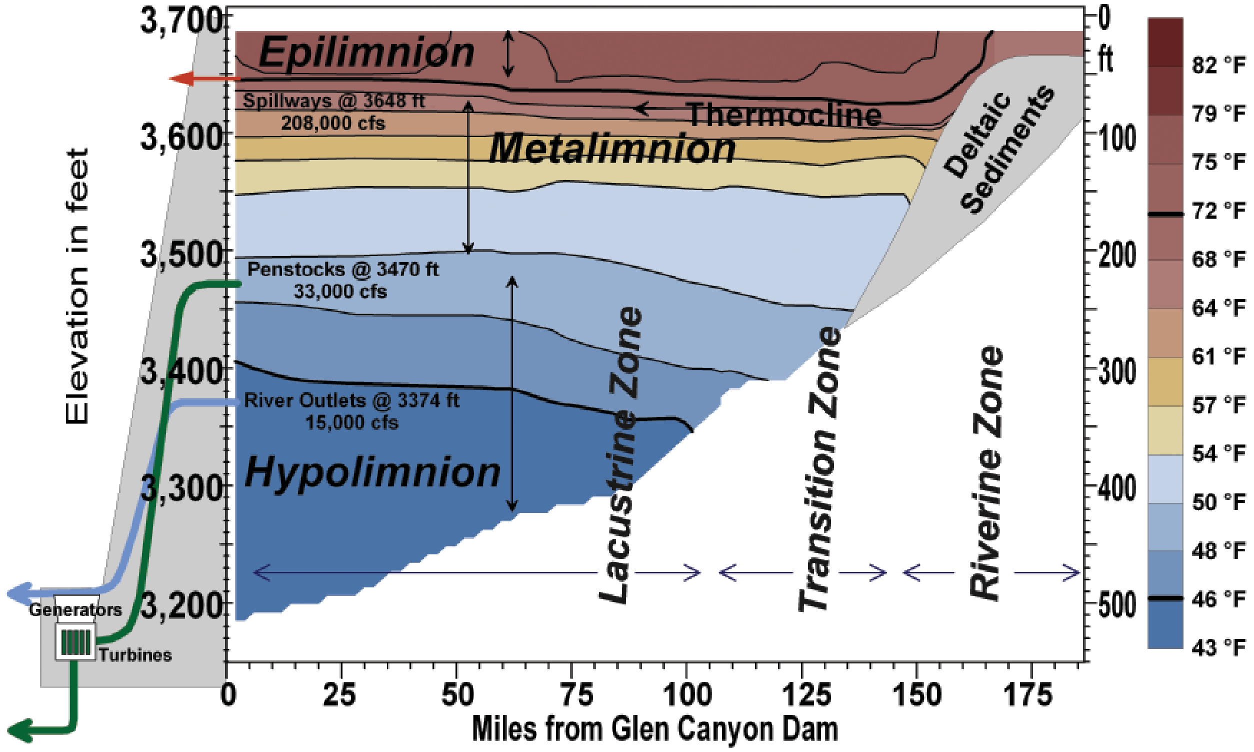

FIGURE 3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado River (Source: Vernieu et al. 2005)

ranges from the reservoir surface to a depth of about 60 ft, depending on season and location (Hart and Sherman 1996; Vernieu et al. 2005), exhibits the highest temperatures within the reservoir and varies little with depth. Warmed by spring inflows, ambient air temperature, and solar radiation, summer temperatures can reach around 25–30°C (77–86°F), while winter temperatures may drop to 6–10°C (45–50°F) (Stanford and Ward 1991; Vernieu et al. 2005; Reclamation 1995, 1999b). The metalimnion typically ranges from 60 to 180 ft in depth and exhibits decreasing water temperatures with depth because sunlight's ability to warm water also decreases with depth (Hart and Sherman 1996; Reclamation 1995). The hypolimnion, which begins around 180 ft below the surface of the reservoir, is typically too deep for sunlight to reach, and water temperatures are lower and remain nearly constant at about 6–9°C (43–48°F) (Vernieu et al. 2005; Hart and Sherman 1996; Reclamation 1995).

During the winter period (November–March), the thermal stratification breaks down as cooling surface waters are mixed with deeper water by the wind and vertical currents. By the end of the calendar year, mixing typically progresses to the depth of the penstock withdrawals. At this point, the release waters begin to exhibit characteristics of the epilimnion, which contains the warmest water in the reservoir at that time of year, despite the cooler weather conditions (Vernieu et al. 2005). Thus, the warmest release temperatures of the year occur in late fall to early winter, then temperatures begin to cool again as vertical currents mix the reservoir down to the penstocks depth, which occurs before thermal stratification begins to reestablish.

During the ongoing drought in the 2000s, Lake Powell levels generally declined and release temperatures gradually began to warm (Vernieu et al. 2005). Since then, total Colorado Basin storage has experienced year-to-year fluctuations in response to wet and dry hydrology, but water temperatures have continued on a general warming trend compared to the early 1990s (refer to Section 3.2.2.3 for further details on Colorado River water temperature). Figure 3.2-5 presents the water temperatures measured at the Lees Ferry gage (the official point of measurement for satisfying compact obligations is at Lee Ferry, Arizona) from 1991–2013, illustrating the aforementioned warming of the Glen Canyon Dam releases. Note that in water year 2011, there was a higher snowpack in the Colorado Mountains which resulted in higher inflows to Lake Powell and unusually large releases of warmwater.

Because of the position of the penstocks (i.e., elevation 3,470 ft), water temperatures can vary both annually and throughout the course of a year because the locations of the epilimnion, metalimnion, and hypolimnion (Figure 3.2-4) depend on season, reservoir level, hydrodynamics, timing and strength of stratification, and magnitude of withdrawals (Vernieu et al. 2005). When reservoir levels are high, releases tend to originate from within the hypolimnion and releases are cooler; when levels are low, withdrawals may come from the metalimnion or upper hypolimnion and releases are warmer (Hart and Sherman 1996). It appears that the water quality of Lake Powell above the dam has been largely unaffected by dam operations, particularly since 1991. Instead, the water quality of the reservoir appears to be more strongly linked to annual to decadal climatological variations, inflow hydrodynamics, and continuing basin-wide depletions (Lovich and Melis 2007; Hueftle and Stevens 2001; Vernieu and Hueftle 1998).

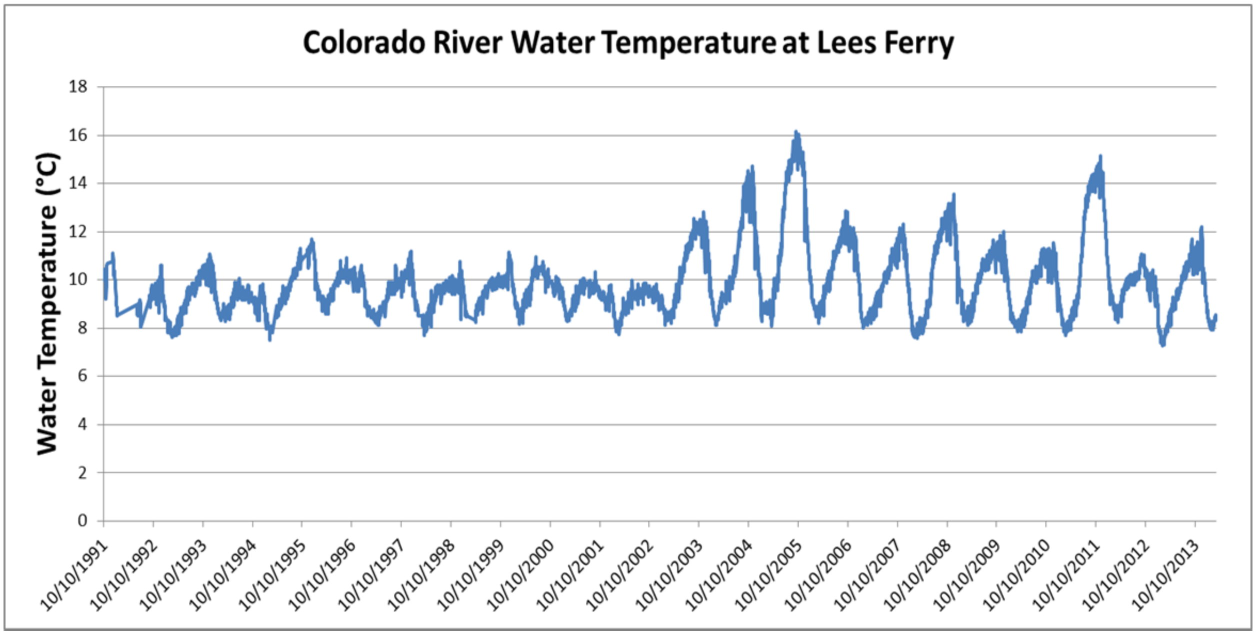

FIGURE 3.2-5 Water Temperature at Lees Ferry (Source: GCMRC 2015a)

Releases from Glen Canyon Dam can have minor effects on water quality and stratification in Lake Powell; such effects can include changes in temperature, salinity, and dissolved oxygen (DO) (Vernieu 2010). The effects on Lake Powell are dependent on the volume and duration of discharges from the dam and on preexisting conditions associated with stratification patterns, location of the layers relative to the release structures, and the fate of inflow currents in the reservoir. In general, the various discharges can cause increased mixing in the reservoir and result in increased movement of horizontal currents through the reservoir, at withdrawal-structure elevations (Vernieu 2010).

DO concentrations in reservoirs are affected by variations in inflow volume and temperature, seasonal reservoir circulation, and biological production and decomposition. In years of high inflows and when the reservoir elevations are low, flows cut through deltaic sediments, resuspending organic matter and nutrients that contribute to both chemical and biological oxygen demand as the inflow water passes down through the reservoir water column. The resulting plumes of low-oxygen water drive water column concentrations lower. When deltaic sediments and organic matter are not resuspended, oxygen demand is decreased and DO concentrations remain higher. Downstream of dams, turbulence, exposure to the atmosphere, and primary productivity reaerate the water column. The DO concentration reaches saturation downstream of Glen Canyon Dam before the confluence with the Little Colorado River (Hall et al. 2012) after passing through several major rapids.

Releases utilizing the bypass structures are made from depths beneath the powerplant intakes. The release waters tend to have lower temperatures, higher salinity, and lower oxygen levels than the water discharged from the dam during normal operations (Lovich and Melis 2007; Hueftle and Stevens 2001).

3.2.2.2 Colorado River Water Quality

The limnology and stratification of Lake Powell, particularly with respect to the location of the penstock intakes, defines the quality of Glen Canyon Dam releases. In general, outflow waters are drawn from the deep zone of the forebay metalimnion into the hypolimnion and characterized as generally even in quality throughout the year, being uniformly cold, clear, below saturation in DO, and low in nutrients (refer to individual Lake Powell parameters in Section 3.2.2.1 for more details). In addition, operation of the dam for peaking power generation has resulted in the removal of much of the seasonal and annual variability that occurred under natural conditions, replacing it with daily fluctuations constrained by set ramping rates (Vernieu and Hueftle 1998; Lovich and Melis 2007). After its release from the dam, changes to the chemical and physical quality of the water are affected by ambient meteorological conditions, primary production and respiration from the aquatic environment, aeration from rapids, inputs from other tributary sources and overland flow, and various aspects of dam operations (Vernieu et al. 2005).

Previous HFEs have been shown to affect the water quality of Lake Powell, the release waters, and Colorado River below Glen Canyon Dam, resulting in slight reductions in downstream temperature and slight increases in salinity, as well as a temporary increase in turbidity (i.e., suspended sediment) from scouring (Reclamation 2011b). In addition, under normal powerplant discharges, limited aeration of the river occurs in the tailwater reach of the river just below the dam compared to reaches farther downstream. However, during HFEs (e.g., high flows in 1996, 2004, 2008, 2012, 2013, and 2014), the effects of the spray and resulting turbulence were sufficient to bring the undersaturated release water up to full or supersaturation oxygen levels immediately below the dam and through the tailwater (Hueftle and Stevens 2001; Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). During HFEs, diurnal DO patterns were still present but were overshadowed by jet tube aeration. These fluctuations recover quickly (within hours) when there is a return to lower flows, although net respiration is typically reduced from pre-flood levels due to the sheared biomass (Hueftle and Stevens 2001). The magnitude of the dam discharges also influences the amount of sediment in suspension, and high water volumes can greatly affect the degree of downstream distribution. Large or widely fluctuating releases draw water from a thicker withdrawal zone than do low or steady releases. Thus, during these events, water has the potential to be either cooler and more saline (if drawn from below the thermocline or released through the jet tubes), or warmer and less saline (if drawn from above) than that typically released (Vernieu et al. 2005).

Downstream of the dam, larger tributaries (e.g., Little Colorado River and Paria River) that enter the Grand Canyon can affect water quality of the Colorado River below Glen Canyon Dam. In general, these tributaries tend to carry water at higher temperatures than the mainstem river, thus warming the regions where they join. In addition, tributaries, such as the Paria River and Little Colorado River, can carry large amounts of fine sediment and organic materials during flood events, which limit light availability for primary production and may enhance conditions for native fish that use turbid water for cover from predation (Cole and Kubly 1976; Shannon et al. 1994; Topping et al. 2000a,b; Vernieu et al. 2005). Some tributaries, such as the Little Colorado River, are also significant sources of salinity for the mainstem Colorado River, while other tributaries are more dilute (Cole and Kubly 1976; Vernieu et al. 2005). There are also a number of smaller spring-fed tributaries that originate within the Grand Canyon reach, which tend to have very different physicochemical properties than the mainstem; however, their mean flows are so low that their contribution to water quality during base flow is not significant.

Colorado River Temperature

Prior to the construction of Glen Canyon Dam, the water temperatures of the Colorado River in the Grand Canyon would range from near freezing (0°C, or 32°F) in the winter to around 30°C (86°F) in the late summer, with a mean of approximately 14°C (57°F) (Cole and Kubly 1976; Johnson and Merritt 1979; Reclamation 1995; Vernieu and Hueftle 1998; Lovich and Melis 2007; Stevens 2007). Before 1973, during the reservoir's initial filling stage, release temperatures were greatly affected by surface or epilimnetic withdrawals because of the proximity of the reservoir's surface to the penstock withdrawal zone. Thus, the maximum release temperatures during that period occurred during the months of August and September, reflecting the surface warming of the reservoir (Vernieu et al. 2005).

Trends in tailwater temperature stabilized from 1973 to 2003, when the reservoir surface elevations were above 3,600 ft. During this time, overall seasonal fluctuations diminished to approximately 5°C (9°F), and release temperatures were greatly reduced because the penstocks of the dam were located well below the surface of Lake Powell in the hypolimnion. The Glen Canyon Dam tailwater temperatures ranged between about 7 and 12°C (45 and 54°F) and averaged about 9°C (49°F) as measured at Lees Ferry, with minor excursions beyond this range during periods of spillway releases (Reclamation 1995, 1999b; Vernieu et al. 2005; Hamill 2009). In addition, an asymmetric annual temperature pattern developed over this period, with tailwater temperature measurements reflecting the seasonal changes of the water at the penstock depth. In general, the highest river temperatures immediately below the dam occurred in late fall or early winter (e.g., December), most likely a result of winter vertical mixing in the upper layers of the reservoir. This is followed by a sudden drop of the river's minimum temperature within a few months, with the lowest temperatures occurring in late winter (e.g., February or March), that likely occurs due to reservoir mixing (Vernieu and Hueftle 1998). Daily warming of the tailwater has also been observed, with the maximum warming (about 1.3°C, or 2.3°F) during the day occurring in June, near the summer solstice (Flynn et al. 2001).

Since the early 2000s, total Colorado Basin storage has experienced year-to-year increases and decreases in response to wet and dry hydrology. However, Lake Powell water levels have generally declined as a result of basin-wide drought conditions, and subsequently release temperatures warmed. For example, in November 2004, the annual maximum mean daily temperature reached its height at around 15°C (59°F) (Vernieu et al. 2005) at the Little Colorado River. Beginning in water year 2005, overall reservoir storage in the Colorado River Basin has increased (Reclamation 2013c), which has apparently caused river temperatures to decline slightly, although they still range between around 8 and 12°C (46 and 57°F) at Lees Ferry. Figure 3.2-5 (in Section 3.2.2.1) presents the water temperatures measured at Lees Ferry from 1991 to 2013, which illustrates the aforementioned warming trend of dam releases.

River temperatures increase as the water moves slowly downstream. This correlation is a function of the distance and time from Lake Powell, as well as the input from tributaries (which are usually warmer than the mainstem) (Cole and Kubly 1976). However, it has been generally estimated that water temperatures increase about 1°C (1.8°F) for every 30 mi traveled downstream (Reclamation 1999b). This downstream warming trend can be seen in Figure 3.2-6, which presents Colorado River water temperatures at four stations along the river from Lees Ferry to Diamond Creek.

The greatest warming occurs during the period from June through August because of the transfer of heat from the warmer surrounding air mass, heat stored in the canyon walls adjacent to the river, and solar radiation. The mean annual downstream river temperatures ranged between 9 and 18°C (48 and 64°F), depending on year and distance downstream of the dam (Reclamation 1995, 1999b; Hamill 2009). In general, water temperature in lower reaches of the river is affected by three physical properties: discharge rate, which affects residence time (Anderson and Wright 2007; Wright, Anderson et al. 2008); channel aspect, which affects light availability; and air temperature, which is generally greater in the western portion of the Grand Canyon (Yard et al. 2005; Ralston 2011). Mainstem water temperatures near the mouth of the

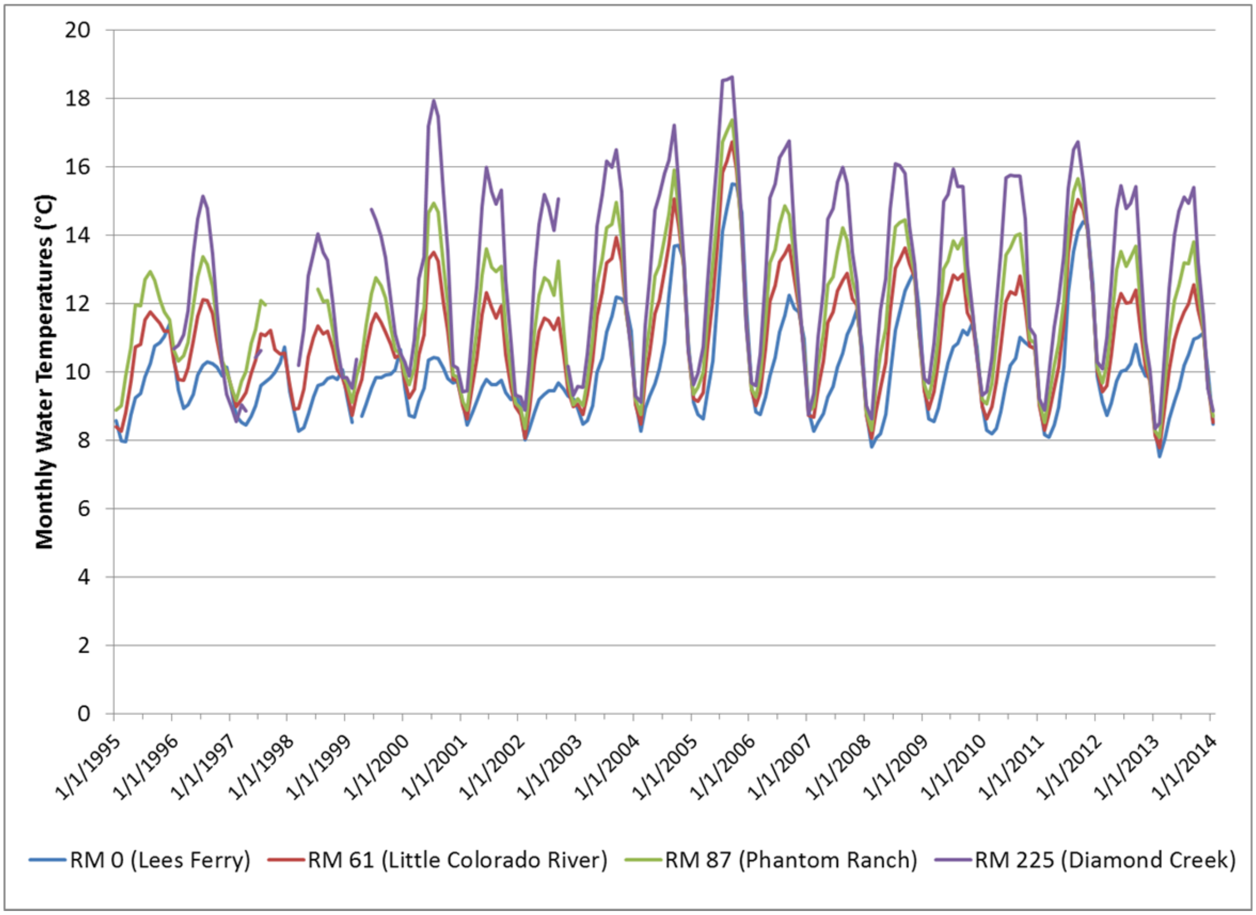

FIGURE 3.2-6 Water Temperatures at Four Stations along the Colorado River from Lees Ferry to Diamond Creek, 1995–2014 (Source: GCMRC 2015a)

Little Colorado River have not reached 16°C (61°F) in July and August unless release temperatures approached 14°C (57°F) (Wright, Anderson et al. 2008). Warmer mainstem temperatures are attainable in the western part of the Colorado River in July, when releases from Glen Canyon Dam are 12°C (54°F), because of the longer residence time of water in the river channel (Ralston 2011).

As illustrated in Figure 3.2-7, a comparison of the increase in weekly average water temperature between Glen Canyon Dam and Diamond Creek to the average weekly flow during mid-June from 1994 to 2004 demonstrates the effect of Glen Canyon Dam releases on warming patterns in the Colorado River in the Grand Canyon. For example, the 1997 high steady flows of approximately 26,000 cfs resulted in 5°C (9°F) warming at Diamond Creek, whereas the low steady flows of 8,000 cfs in 2000 exhibited a 10°C (18°F) warming. This difference is because large volumes of water have greater mass and a lower surface area to volume ratio, as well as less residence time for atmospheric heat exchange that is due to higher velocity, reducing the amount of warming from ambient temperatures and solar radiation. The warming occurring at low discharges also affects water temperatures in the lower Grand Canyon to a greater degree than the elevated release temperatures (Vernieu et al. 2005).

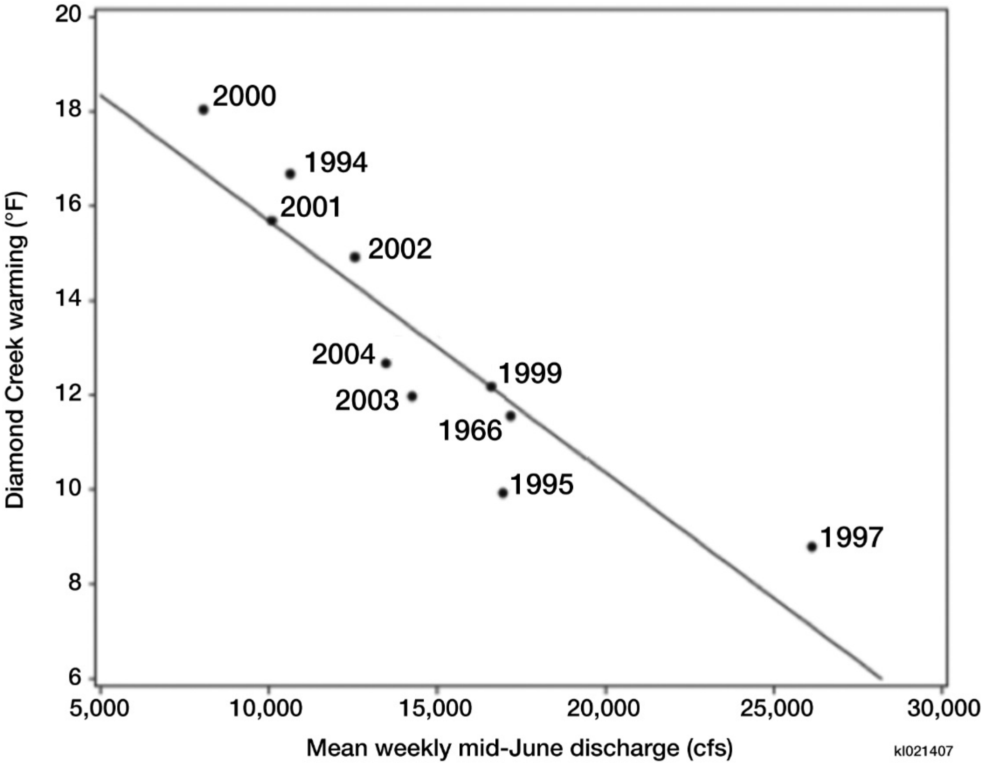

FIGURE 3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek, 1994–2004, as a Function of Mean Weekly Discharge (Source: Vernieu et al. 2005)

Lateral variation in river temperature has also been found to occur throughout the Grand Canyon. Substantial warming takes place in various near-shore environments, ranging from shallow, open-water areas to enclosed backwaters. Water in these environments becomes isolated from mixing with the main channel current and warms (depending on the season) as a result of solar radiation and equilibration with ambient air temperatures (Vernieu et al. 2005; Ralston 2011). According to 2000 data, water-surface temperatures along the shorelines varied from 9 to 28°C (48 to 82°F), with temperatures between 13 and 14°C (55 and 57°F) accounting for the largest proportion of all shoreline areas (Davis 2002; Ralston 2011). Backwaters specifically showed the largest contiguous areas with surface temperatures greater than 16°C (61°F) during the warmest periods. In addition, the area near the confluence with the Little Colorado River shows significant local warming as a result of the tributary inflow. According to 2000 data, mainstem surface temperatures near the Little Colorado River averaged about 13.5°C (56°F), because the cooler mainstem temperatures (typically 12°C [54°F], even in the summer months) are mixed with those of the warmer tributary (typically greater than or equal to 16°C [61°F]) (Voichick and Wright 2007; Protiva et al. 2010; Ralston 2011). In contrast to the mainstem, the Little Colorado River and other tributaries do not appear to have much interannual variation in the range of natural variability after 1990, when regular monitoring began (Stevens 2007).

Colorado River Salinity

Historically, salinity has been a major concern, not only to ecological habitats, but also to water users in both the United States and Mexico. In June 1974, Congress passed the Colorado River Salinity Control Act, which directed the Secretary of the Interior, acting through Reclamation, to implement a basin-wide salinity control program to protect and enhance the water quality of the Colorado River. Since 1974, significant salinity control measures have been implemented and substantial reductions in salinity have been achieved throughout the basin (Reclamation 2013c).

Since the construction of Glen Canyon Dam, the existence of Lake Powell and the amount of water passing through the system has acted to moderate and stabilize salinity levels in both the reservoir and the tailwater (Reclamation 1999b). Salinity below Glen Canyon Dam is typically in the range of 300 to 600 mg/L for total dissolved solids (TDS), with sodium and calcium as the dominant cations and sulfate as the dominant anion (Hart and Sherman 1996; Taylor et al. 1996; Vernieu et al. 2005; Reclamation 1999b, 2005a, 2011c; CRBSCF 2011).

The specific conductance of the Colorado River between the Glen Canyon Dam and Lake Mead has been found to range from 310 to 4,600 µS/cm (approximately 200–2,700 mg/L TDS), with the lowest levels near the mouth of Bright Angel Creek and the highest concentration near the mouth of the Little Colorado River (Taylor et al. 1996; Voichick 2008; Hart and Sherman 1996).

Research has indicated that salinity below the dam changes little with the seasons and shows no regular daily pattern (Flynn et al. 2001; Reclamation 1995). In fact, post-dam salinity fluctuations downstream vary less over several years than the pre-dam cycles changed on the order of months (Reclamation 1995). However, large or widely fluctuating releases draw water from a thicker withdrawal zone than do low or steady releases. Thus, during these events, water has the potential to be either cooler and more saline (if drawn from below the thermocline or released through the jet tubes), or warmer and less saline (if drawn from above) than that typically released (Vernieu et al. 2005).

Colorado River Turbidity

Turbidity levels are of interest in the downstream environment because water clarity affects the amount of light available for photosynthesis for downstream algal communities, which are an important part of the overall food base for native and nonnative fishes. Turbidity also affects the behavior and distribution of various native and nonnative fishes in providing cover from various predators or by affecting sight-feeding abilities (Vernieu et al. 2005). Turbidity is related to several characteristics of suspended sediment (as noted above in Section 3.2.2.2); thus, suspended-sediment measurements have been used as a proxy for determining turbidity in the system. Voichick and Topping (2010) specifically correlated these two values for the Grand Canyon section of the Colorado River and determined a statistically significant relationship between them.

Prior to construction of Glen Canyon Dam, the Colorado River has historically had very turbid water with suspended load averaging between 1,450 and 6,140 mg/L, depending on month, at Lees Ferry (data for the years 1930–1964) (USGS 2013a) and around 8,000 mg/L downstream 80 mi (Cottonwood Creek), with a maximum historical record of more than 150,000 mg/L measured between the mouth of the Little Colorado River and Bright Angel Creek (Cole and Kubly 1976; Johnson and Merritt 1979).

In the post-dam river, the annual supply of sediment has been altered and reduced. More recent measurements have found the concentration of suspended sediment at Lees Ferry to range from approximately 1 to 150 mg/L (data for the years 1996–2012) (Reclamation 2002; USGS 2013b). The amount of suspended sediment downstream of the dam depends primarily on tributary runoff into the Colorado River below Lees Ferry, which can contribute high concentrations to the mainstem during large floods on those tributaries (Voichick and Topping 2010). It also depends on the magnitude and frequency of planned HFEs, which can temporarily increase suspended sediment as a result of scouring in the reach downstream of the dam. Consequently, suspended sediment varies over an even larger range now than it did prior to the completion of Glen Canyon Dam. Post-dam suspended sediment concentrations near the mouth of the Little Colorado River range from approximately 20 to 133,000 mg/L depending on season and year (Cole and Kubly 1976; Taylor et al. 1996). At Phantom Ranch, approximately 87 RM below Lees Ferry and below several tributaries (Paria River, Little Colorado River, and Clear Creek), the suspended sediment concentrations have been found to range from 6 to 47,100 mg/L (Reclamation 2002).

Colorado River Nutrients

Nutrients like nitrogen and phosphorous are necessary for healthy waters, but high levels of nutrients can cause a number of problems, ranging from nuisance algae blooms and cloudy water to threatening drinking water quality and harming aquatic life. In general, releases from Glen Canyon Dam and downstream Colorado River waters are relatively low in nutrients. Tributaries below the dam (e.g., Paria River, Little Colorado River) have somewhat higher nutrient contents than the mainstem, but they appear to contribute little to overall mainstem nutrient concentrations (Reclamation 1995).

Dense populations of the New Zealand mudsnail (*Potamopyrgus antipodarum*) may also affect available nutrients. Dense populations can consume nutrients, and, because they are relatively immune to predation, sequester those nutrients making them unavailable to other species in the food chain (Sorensen 2010). Sections 3.5.1.4 and F.2.1.3 (Appendix F) provide additional information on the New Zealand mudsnail.

The high biomass of filamentous green algae (dominated by *Cladophora glomerata* until 1995; currently *Ulothrix zonata* and *Spirogyra* spp. dominate) observed in the Glen Canyon stretch of the Colorado River below the dam suggests that nutrients may not be a limiting factor. The uptake and cycling of nutrients may be quick enough that there is very little opportunity to sample free dissolved nutrients in the water column of the river; alternately, constant delivery of low concentration nutrient levels are sufficient for the algae to grow (Reclamation 1999b).

Colorado River Dissolved Oxygen

The ideal DO for fish, particularly those in early life stages, is between 7 and 9 mg/L. Most fish cannot survive when DO falls below 3 mg/L (i.e., acute stress), and DO values less than 5 mg/L are considered a chronic stress for fish. DO concentrations in the Glen Canyon Dam tailwater at Lees Ferry typically range from a low of around 6 mg/L in the fall (e.g., October–November) up to a high between 9 and 11 mg/L in the spring (e.g., April–May) (GCMRC 2015a). However, it is significant to note that unintentional fish kills in the Glen Canyon reach were documented in 2005 as a result of low DO levels (approximately 3.5 mg/L), and DO levels in 2014 approached the lethal limit for trout (Arizona Council of Trout Unlimited, Inc. 2015). Thus, while DO levels over the long term do not typically affect the aquatic ecosystem in Glen Canyon, occasional short-term low DO events can negatively impact fish (Kennedy 2016).

The seasonal variation in DO of the Glen Canyon reach of the Colorado River reflects changes in the DO concentration in the water of Lake Powell at the depth of the penstocks (Flynn et al. 2001). In general, Lake Powell DO concentrations are at their highest near the surface of the reservoir in the spring to early summer when inflows are well oxygenated and photosynthetic activities, atmospheric reaeration, and wind-induced mixing are high. During the summer and into the fall, the DO concentrations decrease, primarily as a result of biological reactions. Then, by early winter when the temperatures drop, DO concentrations gradually increase as a result of the higher oxygen-carrying capacity of coldwater and natural mixing processes created by the winter underflow current (Johnson and Merritt 1979; Vernieu and

Hueftle 1998). In addition, as the reservoir ages or if there are periods of extended drought, resuspension of decaying organic matter in upstream deltas can lead to low-DO (less than 5 mg/L) water being released from the dam increase (Vernieu et al. 2005).

DO concentrations increase with distance downstream as a result of aeration, particularly in rapids. Concentrations typically reach full saturation downstream of House Rock Rapid in Marble Canyon (Hall et al. 2012). As previously noted, HFEs can also act to increase oxygen levels immediately below the dam and through the tailwater; however, these effects will recover quickly when there is a return to lower flows (Hueftle and Stevens 2001; Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). Daily oscillations in DO in the tailwater have also been observed at Lees Ferry as a result of activity by the Colorado River algal community. During daylight hours, DO concentrations increase through photosynthesis; at night, a decrease in DO occurs when respiratory processes become dominant (Flynn et al. 2001; Vernieu et al. 2005). The amplitude of the daily DO change at Lees Ferry ranges from around 0.5 mg/L to more than 3.0 mg/L depending on season, with the lowest fluctuations occurring in winter and greatest in spring and summer (GCMRC 2015a).

Colorado River Bacteria and Pathogens

The Grand Canyon's water quality varies greatly in terms of bacteria and pathogens. As development and recreation along the river continue, the potential for an increase of bacterial contamination will continue. Coliform bacteria are a large group of bacterial species that are most commonly associated with water quality. *Escherichia coli* (*E. coli*), one species of fecal coliform bacteria present in the fecal matter of warm-blooded animals, is commonly used in recreational water quality sampling as an indicator of fecal contamination and the potential presence of other harmful organisms (ADEQ 2006a). For fresh recreational waters, the *E. coli* standard criteria is set at 126/100 mL (3.38 oz), with Arizona further defining a single sample maximum of 235 for full body contact and 576 for partial body contact (EPA 2003).

Research has indicated that episodic precipitation cycles and arid watershed hydrology are the principal factors influencing occurrence of bacteria in the river system. Bacterial testing has not indicated a chronic problem in the river, although local occurrences of high coliform bacterial count can and have occurred (ADEQ 2006a; NPS 2005a; Dodson 1995; Tinkler 1992). Fecal coliform in the river and in most tributaries were found to range from 10 to 20 counts/100 mL (3.38 oz) during drought cycles. During wet cycles and storm flows, fecal coliform densities were highly variable and often exceeded recreational contact standards (Tunniclif and Brickler 1984).

Most of the tributaries have high bacterial counts at least some of the time. This bacteria may not be of human origin, but may still result in illnesses. Any stream exhibiting high fecal coliform or fecal streptococcus counts may also carry *Giardia* (NPS 2012a).

3.2.2.3 Lake Mead Water Quality

This section describes the historic and existing water quality constituents that could potentially be affected by the proposed federal action. These water quality constituents of concern include salinity, temperature, sediment, and DO. Other water-quality-related issues and parameters were also considered, but they were determined unlikely to be affected by the LTEMP alternatives, or there was insufficient data to provide an assessment and they are therefore not discussed here.

The Colorado River is the primary hydrologic input into Lake Mead, providing approximately 97% of the total annual inflow. Thus, it is reasonable to assume that the quality of the Colorado River water flowing into the reservoir will have a significant and direct influence on the resulting water quality of Lake Mead. Although a suite of water quality parameters was evaluated for this EIS, four water quality variables were found to be important relative to the effects of Glen Canyon Dam operations. Temperature, salinity, turbidity, and DO of the inflow of the Colorado River into Lake Mead can be affected, particularly by large-volume flows such as HFEs. Because Lake Mead serves as a water supply for Las Vegas and large regions of Arizona, California, and Mexico, changes in Lake Mead water quality have the potential to affect the quality of this water supply.

The temperature of the Colorado River water that enters Lake Mead is influenced by the temperature of water in Lake Powell and to a lesser degree, by monthly and daily release patterns from Glen Canyon Dam. Colorado River inflow temperature is a contributing factor to the small, isolated algae blooms that have occurred in Lake Mead. Two examples of uncommon algal blooms are discussed below to demonstrate how inflow temperatures may affect biological productivity in Lake Mead.

Between February and July of 2001, a reservoir-wide algae bloom occurred and consisted of predominantly the non-toxic green algae *Pyramichlamys dissecta*. The Lake Mead Water Quality Forum's Algae Task Force reviewed the potential factors contributing to the reservoir-wide bloom in 2001, but they could not point to a direct cause of the bloom. Instead, the Algae Task Force indicated four factors that potentially contributed to the 2001 bloom: (1) excessive nutrient runoff from above average winter and early spring rain events; (2) warmwater inflows from the Las Vegas Wash that flowed on the surface of Lake Mead; (3) biological mobilization of phosphorus-rich sediment at the confluence of the Las Vegas Wash and Lake Mead; and (4) seasonally high phosphorus inflows from wastewater treatment plants discharging to the Las Vegas Wash. Although the *Paramichlamys* bloom was not considered a human health risk, the bloom was a deterrent to recreational uses in Lake Mead and contributed to low DO concentrations detrimental to fish. The extent to which the Colorado River flowing into Lake Mead influenced the 2001 algae bloom is unknown, including the attempt to warm river temperatures during the June–September low steady flow experiment conducted the year before the bloom.

Most recently, in 2015, increases in the temperature of water entering Lake Mead contributed to dispersed and periodic blooms of blue-green algae (i.e., cyanobacteria, *Microcystis*) throughout the reservoir, including Gregg's Basin. This type of algae produces multiple toxins, including microcystin and anatoxin, which can affect humans and wildlife. *Microcystis* toxins in water samples from Lake Mead were measured for the first time in 2015.

Colorado River water has a higher density due to its lower temperature and, to some extent, its suspended sediment load. As a result, the Colorado River most often enters Gregg Basin as an underflow, which at times can be seen all the way into Boulder Basin and at the Hoover Dam (Turner et al. 2011; Holdren et al. 2012). This phenomenon also limits nutrient delivery and productivity in the upper levels of the reservoir. During summer months when the temperature differential between Lake Mead and the Colorado River is at its greatest, water entering Lake Mead from the Colorado River plunges to a depth of 65–100 ft in the reservoir's metalimnion, approximately 6 mi downstream of Pearce Ferry (Grand Wash). From this point on, water from the Colorado River exists as a metalimnion interflow and retains its identity, as characterized by lower conductivity, for much of the distance through the reservoir. During winter months, a similar flow pattern occurs; however, the plunge line moves downstream several miles. Cooler winter water temperatures in Lake Mead provide greater mixing due to the decreased amount of energy needed to mix the Colorado River water into the reservoir.

Once Colorado River water plunges, instead of riding the metalimnion just below the thermocline, it drops to a depth of about 260–330 ft, at which point it reaches equilibrium with the reservoir water. The distance traveled before the plume loses its identity is also shorter in the winter due to the greater mixing that occurs, and because of the reduced temperature differential between the two bodies of water (Horn and LaBounty 1997).

Effects on Lake Mead water quality that can occur as a result of changes at Glen Canyon Dam or Hoover Dam, could include changes in salinity, turbidity, and DO in the reservoir (Tietjen 2013), as well as the temperature and water column dynamics influenced by the inflow. In general, higher inflow temperatures have the potential to alter the stratification of the water column, which has resulted in the formation of anoxic conditions in the past. Higher temperatures will also increase metabolic activity in Lake Mead and its sediments. The loading of dissolved and total organic matter to Lake Mead by the Colorado River further influences water quality in the upper reservoir. This material drives oxygen consumption in the sediments and water column in the riverine zone of most reservoirs, and, as such, contributes to observed hypoxia and anoxia.

In Lake Mead, DO concentrations periodically decrease in the bottom waters of Las Vegas Bay, as a result of nutrient and organic matter contributions from Las Vegas Wash and algal growth. In the past and in recent years, low DO conditions have been documented in some isolated parts of Lake Mead near the Colorado River inflow. Ongoing monitoring and investigations are being conducted to determine the cause of such decreases. Currently, elevated temperatures in the Colorado River inflow are the most likely driver. Through an ongoing, multi-agency water quality monitoring program, anoxic conditions were observed in the upper region of Lake Mead in 2014 for a period of 2 months. The warmer Colorado River inflow to Lake Mead altered the typical inflow dynamic, resulting in the river water entering the middle of the water column. This reduced the addition of oxygen to the sediment-water interface and resulted in the development of a 14-mi hypoxic and anoxic region in upper Lake Mead. As with Lake Powell, the stratification of Lake Mead influences many processes in the reservoir, and, consequently, influences characteristics and quality of the water that is released to the Colorado River below the Hoover Dam. Further, DO has not been documented as an issue in downstream reaches.

The formation of Lake Powell in 1963 resulted in marked reductions in suspended sediment loading to Lake Mead, by trapping nearly all of the upstream Colorado River suspended sediment and effectively removing around two-thirds of Lake Mead's previous sediment-contributing drainage area (Ferrari 2008). It has been estimated that between 1935 and 1963, about 0.091 maf of sediment was deposited in Lake Mead each year. However, with the construction of Glen Canyon Dam and the great reduction in suspended sediment load, the life of Lake Mead is now essentially indefinite (Reclamation 2012c). A rough estimate of Lake Mead's current annual sediment accumulation from the Colorado River in the very upper delta portion of the reservoir is less than 7,200 ac-ft (assumes the continual trapping of sediments in Lake Powell and ongoing consolidation of the finer sediments entering Lake Mead) (Ferrari 2008). The amount of finer material entering and settling in the lower reaches of the reservoir is unknown. Dam operations can affect turbidity of the Colorado River inflow to Lake Mead. HFEs may produce increased turbidity in the inflow, although this is also influenced by Lake Mead elevation, stratification, and inflow temperature (Tietjen et al. 2012). Changes in turbidity in upper Lake Mead following HFEs have been observed to persist for weeks following the event and to span more than 25 mi. While the short-term nutrient impacts have been limited, changes in sediment loading to Lake Mead may increase biological productivity in the long term, which may exacerbate the occasional low DO conditions that are already observed. However, HFEs have also been shown to help eliminate low oxygen concentrations or the anoxic region that may develop in the Greggs Basin region of Lake Mead.

The salinity (or specific conductance) of the water in Lake Mead is controlled by a set of interrelated factors, including relatively low values originating from the Colorado River, higher values in the small Muddy and Virgin River inflows; concentration of salts by the evaporation of surface waters, and the influence of water column stratification in seasonally limiting water column mixing and dilution. As a result, salinity concentrations have cycled during this time period (conductivity values were spread over an approximate 100 µS/cm range), specifically in response to the volume and quality of Colorado River water being released from Lake Powell (Tietjen et al. 2012). For example, as Lake Powell releases water of lower or higher salinity into the Colorado River downstream, the average salinity levels of Lake Mead's water column will similarly decrease or increase, respectively.

3.2.3 Tribal Perspectives on Water Resources

It is important to note that, in the broadest sense, all sources of water (e.g., springs, washes, ponds, pools, lakes, and rivers) are culturally and spiritually important to the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and the Southern Paiute Tribes.

For the Hopi, water is the most precious resource, because it is the basis of life. The cycle of water is at the core of all Hopi ceremonies, and all things related to water—including the plants and animals associated with it—need to be respected and protected. It is a link between current Hopis and their ancestors. It forms the basis for the farming lifestyle that has sustained the Hopi people for thousands of years. Finally, the Colorado and Little Colorado Rivers figure prominently in Hopi clan and ceremonial history.

The Havasupai are the Havsu w 'Baaja, the people of the blue-green water in their native language. Both the Havasupai and Hualapai consider the river the backbone, or *Ha'yiđađa*, of the landscape and to have healing powers (NPS 2006a). The importance of water is evident for the both Tribes as evidenced by inclusion of water in their Tribal seals. The Hualapai worldview holds that the Colorado River provides a life connection to the Hualapai as it flows through the landscape, connecting the canyon and the riparian ecosystems that sustain the Tribe. The historic trails in the Canyons and across the Coconino Plateau include sacred springs as stopping points. The Havasupai religion and culture are closely connected to springs through songs and stories (Hirst 1985).

The Zuni religion is focused on the blessings of water, a gift that is considered to be the ancestors themselves (Chimoni and Hart 1994). The waters of the Colorado River are described as "definitely sacred," according to Alex Seowtewa. Even dry washes are important. The Zunis deem them "passageways" for water, whether or not water flows there year-round. Long before the Americans first ever saw and named the Colorado River, the Zuni named this watercourse *K'yawan' A:honanne*. The name itself speaks to a time before the U.S. government dammed the river, when its waters flowed red from the crimson-hued soils its currents carried. Zunis feel a general sense of sacredness for this body of water. As Octavius Seowtewa explained, "Our respect, our heritage and traditions believe this river has significance for our religion and way of life."

Excerpt from a Ne'we:kwe Medicine Society's ceremonial prayer (shared by Seowtewa)

When the world was created, within the four Great Oceans and waterways (North Pole, South Pole, and Atlantic, Pacific Oceans)
Our Father that stayed behind and flourished
The Feathered Serpent
The Water Snakes
The Fish
The Turtle
The Tadpoles
The Toads
The Frog
The Water Boatman and all aquatic life . . .

And all the protectors of the waters
The Crane
The Geese
The Ducks
The Coots
The Grebes
The Orioles
The Mockingbirds
The Nuthatch
The Wren
The Egrets
The Father Sun – Mother Moon
The Creator
These are the Givers of the Breath of Life
The Aged and the Wisdom
The Water of Life
The Seed of Life
The Belongings of Life
The Offsprings of Life
The Strength
And the rest of the Givers of Life

I ask for their breath
If all goes accordingly and the breath of our fathers are respected
We will all see our fathers rising and setting sun
Arm in Arm
Strength in connection
We will all grow old in wisdom
Now I ask the fathers for that Breath
For the Breath of Life for all

The river is associated with the Zuni people's emergence and first migrations; it is home to aquatic life that is important to Zuni traditions; the water from the river is used in ceremonies; and the waterway is a literal trail and a metaphorical umbilical cord that is linked directly to the Zuni home area via the Little Colorado River (Hart 1995). Seowtewa continued, "My medicine society talks about all the water life; it's all mentioned in my prayers. So any disturbance of water life impacts my religion and way of life. I was taught to respect all life and now damming the river and pumping water [creates…] a spiritual impact on our medicine practices. When you are a religious head you have to take care of even the lowliest form of life, even the stink bug, even the rocks, anything that is on the land." This statement parallels previously documented Zuni values of the river. As Dongoske et al. (2010) wrote, "The Colorado River itself is regarded as an important conscious living being that has feelings, and is expressive of calmness and anger. The river can offer happiness, sadness, strength, life, sustenance, and the threat of death. According to many of the Tribal beliefs, if a land and its resources are not used in an appropriate manner, the Creator will become disappointed or angry and withhold food, health, and power from humans."

Zunis pray for water; they pray at water sources; and they use water in religious ceremonies. Cushing wrote that the Zuni "consider water as the prime source of life" (Green 1979). As Dickie Shack, a Zuni religious leader and cultural advisor, explained, "The whole world has water and it's all precious to us. We get it and bring it here for our religious stuff. We use it in paint for our prayer sticks—it's so important to get rain. So this water is precious to us. If I go to the Grand Canyon, I'll get me water there. I believe the rain is our fathers. Anywhere there are springs we hold out hand and say, 'come with us to Zuni village' and we pour the water on our heads." Mr. Shack added, "In my Rain Priest doings, we pray for all directions, to the ocean, to our grandfather, Ko'lowisi, the serpent, in all directions. We say prayers so that they'll help us with rain. So all this water around the world, even the ponds, it's very important to us, for us to say prayers because we need rain in Zuni" (Colwell-Chanthaphonh et al. 2011).

Further emphasizing the importance of all water life to the Ne'we:kwe Medicine Society, the textbox provides an excerpt from one of the ceremonial prayers shared by Seowtewa. Speaking about Glen Canyon Dam, Seowtewa stated, "They put the dam in without consultation, and ... the dam restricted the umbilical cord. It's like when you're in your mother's womb and there's a knot in the cord, then there's a problem" (Colwell-Chanthaphonh et al. 2011).

The present Navajo world begins at Hajiinai, the Place of Emergence. The people began their journey through several underworlds until they finally emerged into this world filled with water. After this world was given to us by the Holy People, they cleared the water away. The Humpback God stood in the center of the world and dragged his cane from east to west and created the canyon. The water drained and created rivers and creeks which then became the veins of the earth. In the canyon there are also places of clan origins and migrations, specifically for the Tl 'izilani (Manygoats) clan and a branch of the Anaasazi Tachii 'nii clan. Sodizin (prayers) are still offered at these places and will continue to be in the future. Plants from the Canyon are used for food and medicine, and minerals such as salt and red ocher are still gathered for use in ceremonies and in everyday life (Roberts et al. 1995).

3.2.4 Hydrology and Climate Change

Global climate models,[4] covering a range of possible future emissions scenarios, project that temperatures will increase globally by about 1.1 to 6.4°C (2 to 11.5°F) by the end of the 21st century (2090–2099; relative to 1980–1999 values) (Solomon et al. 2007). Although global predictions and trends cannot predict changes at the regional level with certainty, regional temperatures are also expected to increase. Average estimates for the Colorado River Basin indicate a projected 5 to 6°C (9 to 10.8°F) increase during the 21st century, with slightly higher increases projected in the upper Colorado Basin (Reclamation 2011e). Predictions also suggest a general drying trend (although the full range of predictions includes both wetter and drier conditions) for mid-latitude areas such as the Colorado River Basin (Reclamation 2007a; Vano et al. 2013; IPCC 2007).

Observations and studies have also shown that many natural systems are being affected by regional climate changes, particularly the aforementioned temperature increases, and that these changes will likely affect the hydrological cycle, with associated impacts on water resources. The following sections summarize the potential effects of increasing temperatures on the broad-scale features of Colorado River Basin hydrology and water resources; other aspects related to climate change (e.g., meteorology and air quality) are discussed in Section 3.16 of this EIS.

3.2.4.1 Basis for Runoff Estimates

The most likely hydrological changes expected as a direct consequence of warmer temperatures are linked to water variability and availability (described in more detail in Section 3.2.4.2), which is mostly influenced by the amount of runoff in the basin (Reclamation 2007c). The conventional assumption used in water resources planning is that the past record of runoff can be used to represent future conditions; in other words, that the future will look like the recent past. However, there are limitations to these assumptions; it is possible that future flows may include periods of wet or dry conditions that are outside the range of sequences observed in the historical record, particularly considering the effects of climate change and the potential for increased hydrologic variability. Furthermore, considerable evidence from paleontological records indicates that the observed record of the last 100 years does not capture the full range of variability of historical stream flows in the Colorado River (Reclamation 2007c; Vano et al. 2013). In fact, the early 20th century, which is the basis for water allocation decisions in the basin, was a period of unusually high flow (Vano et al. 2013). Tree ring records indicate that the Colorado River Basin has experienced severe droughts in the past and could do so again, even without human-caused climate change (Vano et al. 2013). Thus, although paleoclimatic information may not necessarily represent future climate conditions, this information is valuable

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[4] Refer to Solomon et al. (2007) for further detail related to the global climate models used for the projected temperature rise.

and may be useful in understanding variability in future hydrologic sequences, particularly with respect to the potential for drought (Reclamation 2007a).

3.2.4.2 Water Variability and Availability

In general, the water supply of the Basin is strongly dependent on snowmelt from high-elevation portions of the Upper Basin, with about 15% of the watershed area producing about 85% of the entire basin's average annual runoff. Annual precipitation ranges from less than 4 in. in southwestern Arizona to nearly 63 in. in the headwaters in Colorado, Utah, and Wyoming (Reclamation 2011e). The western states have heated up more than the world as a whole has (Saunders et al. 2008). In 2003–2007, the global climate has averaged 1°F (0.56°C) warmer than the 20th century average. For the same period, the 11 western states averaged 1.7°F (0.94°C) warmer than the 20th century average. By state, average temperature increases range from 1.3°F (0.72°C) in New Mexico to 2.2°F (1.2°C) in Arizona. To date, decreases in snowpack, less snowfall, earlier snowmelt, more winter rain events, increased peak winter flows, and reduced summer flows have been documented (Saunders et al. 2008).

Water storage is very sensitive to changes in mean inflows and to sequences of wet and dry years. As noted previously, although precise regional estimates of the future impacts of climate change on runoff throughout the Colorado River Basin at appropriate spatial scales are not currently available, these impacts may include decreased mean annual flow and increased variability, including more frequent and severe droughts. Overall changes to precipitation would likely decrease the rain and snow that drains into the Colorado River Basin; however, estimates have suggested that by 2050, Upper Basin precipitation may increase slightly (i.e., 2.1%), while that in the lower basin declines similarly (i.e., 1.6%) (Reclamation 2011e). Furthermore, warmer temperatures alone would be expected to increase water losses (e.g., evapotranspiration from vegetation, evaporation from reservoirs, and sublimation) and reduce runoff flow (Reclamation 2007a; Vano et al. 2013; Reclamation 2012e).

Estimated declines of future runoff for the Colorado River Basin range from less than 3.5% to 45% by the mid-21st century (Vano et al. 2013; Reclamation 2011e). The wide range in projected flow decreases results from the following factors:

- Variability among climate models and future emissions scenarios used to generate the estimates;
- Spatial resolution of the model, which is important for capturing topography and its effect on the distribution of snow in the Colorado River's mountainous headwaters;
- Representation of land-surface hydrology, which determines how precipitation and temperature changes affect the land's ability to absorb, evaporate, or transport water;

- Methods used to statistically downscale from the roughly 124-mi resolution used by global climate models to the 6.2- to 12.4-mi resolution used by regional hydrology models; and

- Model uncertainties, including the uncertainty in the climate response, as well as the uncertainty due to differences in methodological approaches and model biases (Vano et al. 2013; Reclamation 2007a).

As discussed in the *Colorado River Basin Water Supply and Demand Study* (Reclamation 2012h), the general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (due to lower precipitation), greater evaporation and evapotranspiration losses (due to higher temperatures), and increased demand (due to increased population size). Combined, these factors increase the probability and likely duration of delivery shortages in coming decades. It has been estimated that the shortfall created by future supply and demand imbalances could range from 2.3 to 4.1 maf per year, during any given deficit period (Reclamation 2012e). When climate change considerations are taken into account, this value increases to around 7.4 maf per year during the deficit period (Reclamation 2012e). These considerations would affect all of the LTEMP alternatives equally.

3.2.4.3 Seasonal Timing Shifts

Warmer conditions are also expected to lead to shifts in the precipitation events and seasonal timing of runoff (i.e., transitioning snowfall to rainfall) with increased winter runoff (December to March) and decreased summer runoff (April to July) (Reclamation 2011d,e, 2013c; Brekke et al. 2009). This shift in timing could present challenges in managing streamflow, especially under current reservoir operational constraints. Storage opportunities during the winter runoff season currently are limited by flood-control considerations, and increased winter runoff under climate change will not necessarily translate into increased storage of water leading into the spring season. Conversely, reservoir storage capture of snowmelt runoff traditionally has occurred during the late spring and early summer seasons. Reductions in runoff during this season likely would translate into reductions in storage capture and, likewise, reductions in water supply for warm season delivery (Reclamation 2013b). Increasing temperature may also increase potential evapotranspiration from vegetation and land surfaces and may thereby decrease the amount of water that then reaches streams, lakes, and reservoirs (Brekke et al. 2009).

There may also be changes in seasonal patterns in relation to extremes of precipitation. Depending on location, these possible changes can and have led to concerns that droughts and floods, defined relative to past experiences, will occur more frequently and/or be more severe under future climate conditions. However, because of uncertainties in climate models and flood record analyses, the nature of changes in specific locations remains uncertain and will require detailed study (Brekke et al. 2009).

3.2.4.4 Water Quality

Water quality is also greatly affected by the changing precipitation and temperature that result from climate change. For example, increasing air temperatures may lead to increased water temperature, which can affect the chemical properties of water and habitat suitability. Altered water temperature in the reservoirs also influences the potential for algal blooms, which can further reduce oxygen levels. In addition, changes to precipitation intensity and frequency (i.e., water availability) can also influence concentrations of suspended sediment, nutrients, and chemical contaminants originating from tributaries, as well as non-point-source pollution from runoff (e.g., agricultural fields, roads, and other land surfaces) (Brekke et al. 2009).

3.3 SEDIMENT RESOURCES

This section describes the sediment resources of the affected area. Sediment is defined as unconsolidated material derived from the weathering of rock that is transported and deposited by water or wind. Sediments can be described based on their particle size such as clay, silt, sand, gravel, cobble, and boulder (Section 3.3.2.1). In this EIS, the use of the term sediment refers to the full range of sediment sizes found in Glen, Marble, and Grand Canyons and references specific sediment size ranges using the terminology described in Section 3.3.2.1. For this EIS, the sediment size of greatest concern is sand. Dam operations have an important effect on sand distribution in the affected area, and sand transport and deposition are greatly affected by the characteristics of dam operations. Sand deposits above the elevation of normal operations provide for important areas for vegetation, wildlife, and visitors to GCNRA and GCNP.

3.3.1 Background: Geomorphology of the Colorado River

Geomorphology describes the geologic evolution and configuration of landforms and the processes that shape them. The processes by which sediment is formed, transported, and deposited within the system are largely functions of the geomorphic setting through which the Colorado River and its tributaries flow, and the characteristics of rock formations, faulting, and fluvial processes. These factors generate several distinct geomorphic features, such as turbulent rapids, tranquil pools, talus slopes (rock slides), channel-margin areas, terraces, canyon walls, debris-flow deposits, fan-eddy complexes, and sandbars (see Figure 3.3-1). There have been numerous studies regarding these geomorphic features within Glen, Marble, and Grand Canyons. This research has been used to develop conceptual models of how these geomorphic features interact with river hydraulic and sediment-transport processes.

The Colorado River follows a meandering path as it flows between the canyon walls. Below Glen Canyon Dam, the river varies with respect to its channel geometry (width, depth, and slope), sediment inputs, bed materials, and hillslope deposits, as well as the topography and geology of the surrounding watershed. Valley width is most affected by the type of rocks near the river level, such that resistant rocks exposed at or near river level (e.g., Vishnu Schist) create narrow valleys, and easily eroded rocks (e.g., Bright Angel Shale) create wide valleys. The level

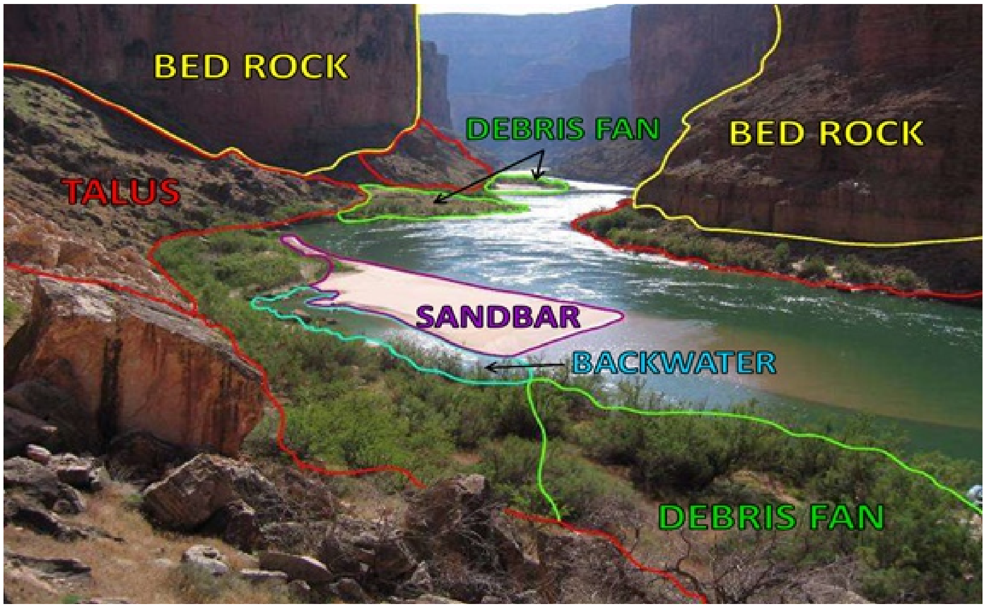

FIGURE 3.3-1 Geomorphic Features of the Colorado River

of bedrock fracturing, which is also a function of bedrock resistance, affects the frequency of tributary debris fans and deep pools (Howard and Dolan 1981).

Schmidt and Graf (1990) defined 11 geomorphic reaches within Marble and Grand Canyons based on parent geologic materials, width-to-depth ratios, slope, and relationship to the confluences with major tributaries. These 11 geomorphic reaches are often described as either narrow or wide reaches based on the width of the canyon in that region. A coarser view of the study area, as used in this EIS, considers three main sections bounded by Glen Canyon Dam, the Paria River, Little Colorado River, and Lake Mead. Beginning at Glen Canyon Dam, the first portion of the river is the 15-mi stretch that runs downstream through Glen Canyon to just upstream of the Paria River at Lees Ferry (RM 0). Glen Canyon has a substantially different geomorphic structure compared to the reaches farther downstream, and it has a limited sediment supply. The next section of river is the approximately 62-mi stretch that runs through Marble Canyon. This stretch starts at the mouth of the Paria River at Lees Ferry (RM 0) and extends to just upstream of the Little Colorado River (RM 61.5). The sediment load of this reach is dominated by Paria River inputs. The third section runs through the Grand Canyon and comprises the remainder of the river downstream of the Little Colorado River. The sediment load of this third portion is the cumulative supply provided by contributions from the Paria River reach, the Little Colorado River, and various other small tributaries.

3.3.1.1 Geomorphic Features of the Colorado River

Fan-Eddy Complexes

The areas along the river where a tributary debris fan partially blocks the flow are commonly referred to as fan-eddy complexes (Schmidt and Rubin 1995; Schmidt et al. 2004). Formed at the mouths of tributary canyons, debris fans are sloping deposits of poorly sorted sediment ranging in size from clays and silts to larger boulders. Deposited by tributary debris flows, debris fans and their associated processes play a significant role in defining the geomorphic characteristics of the Colorado River in Marble and Grand Canyons (Webb et al. 1988; Reclamation 1995; Yanites et al. 2006).

Debris fans extending into the Colorado River obstruct the channel, making it narrower and raising the bed elevation, which forms rapids (or riffles) through the point of constriction, and the downstream-directed current becomes separated from the riverbank (Griffiths et al. 1996) (see Figure 3.3-2). Downstream from the constriction, the channel is typically wider, the main current reattaches to the riverbank, and some of the water is redirected upstream (Schmidt and Graf 1990). This change in flow direction forms a zone of low-velocity recirculating water (i.e., an eddy) between the points of separation and reattachment and between the main channel and riverbank (Rubin et al. 1998). These conditions allow for sediment to become entrained within the recirculation zone where the lower velocities enhance the potential for sediment deposition (Schmidt and Graf 1990; Schmidt and Rubin 1995). Figure 3.3-3 presents a cross-sectional diagram demonstrating how these complexes can trap sediment and work to build sandbars. In this instance, water with relatively high sand concentration (near the streambed) moves toward the eddy and builds a sandbar; water with relatively low sand concentration (near the surface) moves from the eddy back to the main channel (Reclamation 1995).

The deep pools that form upstream from rapids (see Figure 3.3-2) provide space for the temporary storage of substantial amounts of riverbed sediment (e.g., sand and gravel). For a given flow, the constriction width and riverbed elevation at a rapid control the velocity and water surface elevation of the upstream pool, which in turn control the amount of sand and gravel that can be deposited in the pool. Aggraded debris fans will allow the channel to store more sand in the associated pools and eddies.

Nearly all sandbars in the Grand Canyon are associated with fan-eddy complexes. In general, these complexes generate consistent sandbar features, which include separation bars and reattachment bars, based on their specific locations within the recirculation zone (Schmidt and Grams 2011a). They continuously exchange sand with the river. Thus, the sandbars commonly found along the banks of the Colorado River are generally dynamic and unstable. Separation bars form along the downstream face of a debris fan, and reattachment bars form outward from the downstream point where the recirculation zone meets the channel bank (see Figure 3.3-2).

Sandbars form a fundamental element of the river landscape (Figure 3.3-1) and are important for vegetation, riparian habitat for fish and wildlife, cultural resources, and recreation (Wright, Schmidt, et al. 2008; Reclamation 1995). For example, they form the substrate for

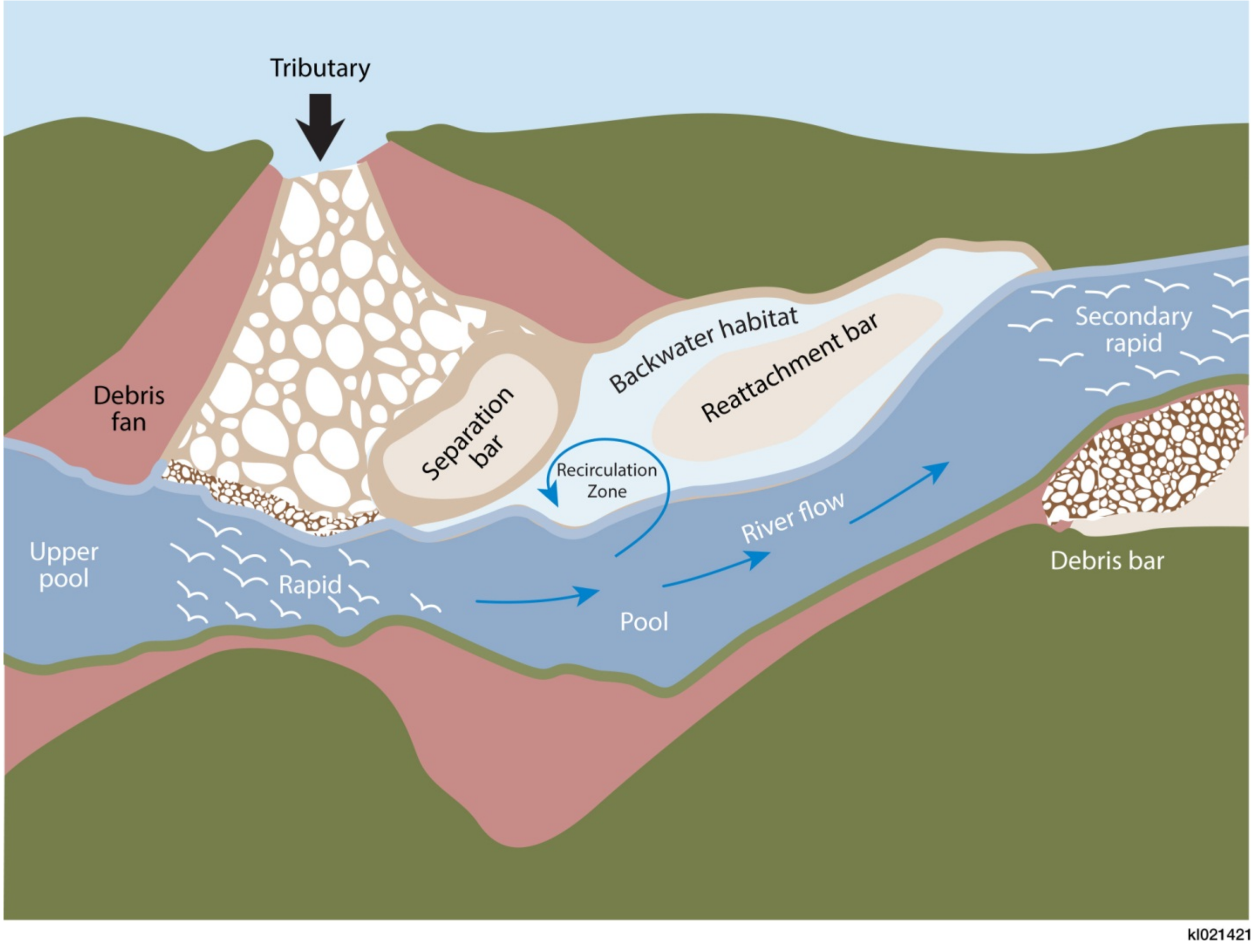

FIGURE 3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River (Source: Webb and Griffins 2001)

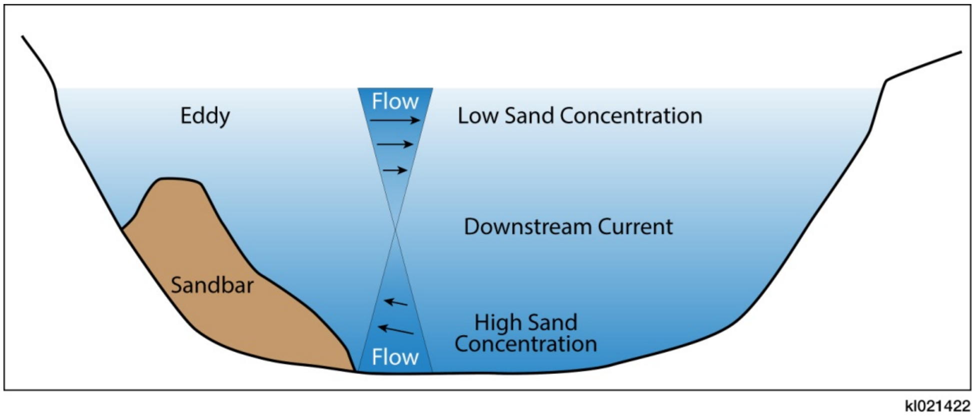

FIGURE 3.3-3 River Cross Section Depicting Sediment Entrapment and Sandbar Building (Source: Reclamation 1995)

limited riparian vegetation in the arid environment. Low-elevation sandbars create zones of low-velocity aquatic habitat (i.e., backwaters) that may be utilized by juvenile native fish. These low-elevation sandbars are also a source of sand for wind transport that may help protect archaeological resources. In addition, beaches provide recreational value for visitors (e.g., camping areas for river and backcountry users). For recreational use (e.g., camping and boating), visitors generally prefer separation bars over reattachment bars because they are composed of finer grained sand, experience less frequent inundation by rising river levels, and have lower velocity conditions for mooring boats (Reclamation 1995).

Fan-eddy complexes also produce important ecologic niches in the canyon. For example, stagnant return-current channels within eddies can support riparian vegetation, attract native fish (e.g., humpback chub), and provide stable substrate for other aquatic organisms (e.g., algae) (Schmidt et al. 2007; Webb and Griffiths 2001).

High Terraces

High-elevation terraces found in reaches of Glen and Grand Canyons support native vegetation and desert riparian communities and may contain buried or partly buried archeological remains. These terraces can be referred to as Holocene terraces because they were formed during the Holocene Epoch (i.e., the time since the last ice age). They were originally formed as sandbars as part of fan-eddy complexes during large natural pre-dam flood events (100,000 cfs and greater; for comparison, current operations have a maximum discharge of 45,000 cfs under normal operations). In general, larger flood flows resulted in higher terraces, and higher terraces are generally indicative of older deposits (Schmidt and Grams 2011a; Reclamation 1995); however, other factors, such as new large tributary debris flows, can also produce terraces under similar flow conditions.

Aeolian, or windblown, deposits can occur on high-elevation terraces and on sandbars near the river, as pictured in Figure 3.3-4. These deposits are generally supplied by sediment blown by wind from the active river channel and are termed “source-bordering” aeolian (dune) deposits (Draut 2012a; East et al. 2016). The supply of aeolian sediment from the active river channel can vary due to environmental factors and river regulation for source-bordering aeolian sediment deposits (Draut 2012a; East et al. 2016). As such, source-bordering aeolian deposits that are not currently significantly supplied by windblown sediment from the active river channel are classified as relic and are considered to be largely derived from older sediment emplaced in high terraces (East et al. 2016; Draut 2012a; Draut and Rubin 2008). Source-bordering aeolian deposits that are contemporarily supplied with sediment blown by wind from the active river channel and sandbars are classified as modern (East et al. 2016; Draut 2012a; Draut and Rubin 2008). Relic deposits are river sediment that is largely inactive with respect to aeolian transport because of a lack of replenishment of sediment from the active river channel and colonization by vegetation and biological soil crusts (Draut 2012a; East et al. 2016). For modern deposits, activity is largely controlled by prevailing wind direction and the amount of bare, dry sand surface area available on the deposit and the upwind sediment source area (Draut 2012a; East et al. 2016).

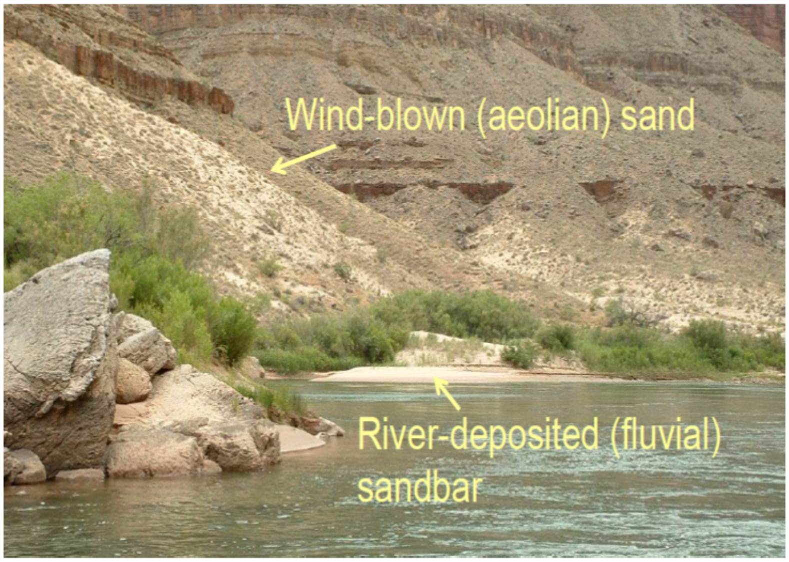

FIGURE 3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River (Source: Draut 2012b)

3.3.1.2 Glen Canyon Geomorphology

The river immediately downstream of Glen Canyon Dam was intentionally scoured in 1965 during a series of high-pulse flows, with the intent of raising the elevation of Lake Mead and scouring the reach immediately below the dam in order to increase the efficiency of the powerplant (Topping et al. 2003). During the initial pulse flows, approximately 5.0 million tons of fine sediment was scoured from Glen Canyon between the dam and Lees Ferry over a period of 3 months. In addition, approximately 17.62 million tons of material was scoured from the reach between Lees Ferry and Grand Canyon gaging stations near Phantom Ranch (Topping et al. 2003; Wright et al. 2005). These pulse flows, coupled with other dam operation activities, transformed the pre-dam Glen Canyon, which had plentiful sand, native species, and active natural processes, to a present-day Glen Canyon that is incised, narrowed, and armored (Grams et al. 2007).

Glen Canyon exhibits a low gradient and has few debris-fan deposits and small riffles. The Colorado River through Glen Canyon can be generally characterized as a stable gravel and cobble-bedded channel that is more similar in character to a cold Alpine headwater stream than a lowland desert river (Schmidt and Grams 2011b). For example, the average grain size of bed material has increased from 0.25-mm sand particles in 1956 to gravel particles larger than 20 mm in 1999 (Grams et al. 2007).

The flow and sediment supply conditions created by the closure and operation of the dam have resulted in bed incision, sediment evacuation, and abandonment to a large degree of any significant sandbar or terrace development in Glen Canyon. Despite this, several large sandbars exist at established recreational sites. The amount of material scoured is equivalent to a cumulative volume about 10.7 million m^3, or a 6- to 10-ft drop in channel elevation averaged over the entire reach, ending at the Paria riffle (Schmidt et al. 2004; Wright et al. 2005). This material is not being re-deposited because no major sediment source exists upstream of the Paria River, making sediment a non-renewable resource in modern-day Glen Canyon (Grams et al. 2007). Previously active sandbars, which have been transformed to gravel bars, are also no longer inundated. Based on repeated surveys in Glen Canyon, the channel appears to have adjusted and stabilized to the regulated flow regime, and the rate of erosion has declined since 1984 (Grams et al. 2007). Although the rate of erosion has declined, the remaining pre-dam high-terrace deposits in Glen Canyon are subject to ongoing erosion processes from the Colorado River and ephemeral tributaries (Anderson 2006; Pederson et al. 2011).

3.3.1.3 Marble and Grand Canyon Geomorphology

The longitudinal profile of the river consists of long, flat pool reaches with intermixed short, steep rapids. The water surface elevation of the Colorado River drops from 3,116 ft to 1,336 ft over the 226 mi from Lees Ferry to Diamond Creek. However, the majority of this elevation change (between 50 and 66%) occurs through the numerous rapids in less than 10% of the river's length (Leopold 1969; Magirl et al. 2005). The rapids are typically associated with debris-fan deposits formed by tributary debris flows (i.e., fan-eddy complexes described in Section 3.3.1.1), which constrict the channel width, causing an upstream pool formation, steep rapids, and downstream scour hole and pool formation (Dolan et al. 1978; Howard and Dolan 1981; Melis et al. 1995) (Figure 3.3-2). For the Colorado River below Lees Ferry, the locations of debris-fan deposits and rapids, as well as the associated changes in channel width and surface water elevations, have also been quantified (Magirl et al. 2008). Figure 3.3-5 depicts the number of debris fans per RM and the variation in water-surface elevation and channel width for modeled river flows of the Colorado River below Glen Canyon Dam (Schmidt and Grams 2011a).

Sandbars throughout the Colorado River, particularly those below Lees Ferry, tend to be associated with fan-eddy complexes and located in pool regions immediately downstream of debris fans (Dolan et al. 1978; Howard and Dolan 1981). It has been estimated that fan-eddy complexes cover approximately 20% of the total water surface area of the river downstream of Lees Ferry (Schmidt et al. 2004). As described previously in Section 3.3.1.1, sandbars are dynamic because of the continual reworking of the sandbar by erosional and depositional processes, which are further described in Section 3.3.2. In general, sandbars are erosional features that can aggrade due to deposition during flood flows.

One of the main resource considerations for sandbars in Marble and Grand Canyons relates to available campsites and campable areas, which is based on considerations of the size, slope, sediment material, and vegetation abundance of a sandbar (see Section 3.11.2 for more details). A comparison of sandbars used as campsites, based on inventories conducted in 1973, 1983, and 1991 (Figure 3.3-6), indicated that the number of campsites increased in both narrow and wide river reaches as a result of a flood in 1983. However, by 1991, erosion reduced the number of campsites to levels closer to the 1973 inventory values. The same study also noted that vegetative overgrowth further reduced the number of campable sites (Kearsley and Warren 1993). According to a study compiled by USGS and cooperating scientists, the open

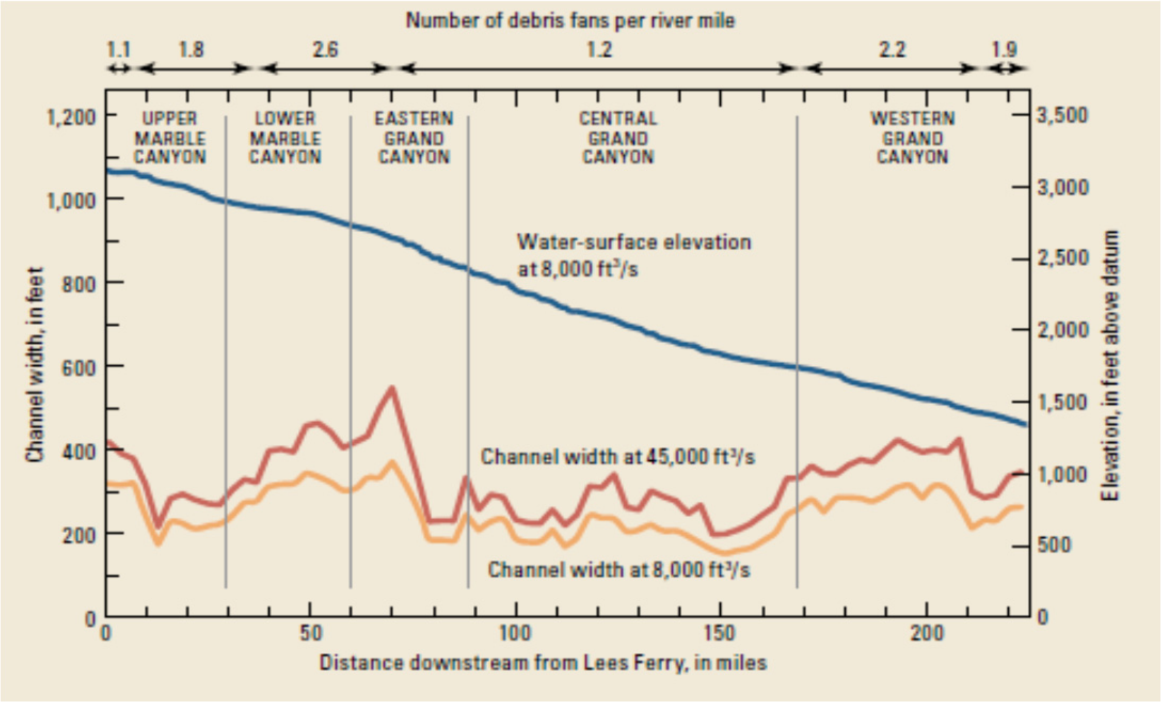

FIGURE 3.3-5 Debris Fans and Variation in Water-Surface Elevation and Channel Width for Colorado River Flows below Glen Canyon Dam (Source: Schmidt and Grams 2011a)

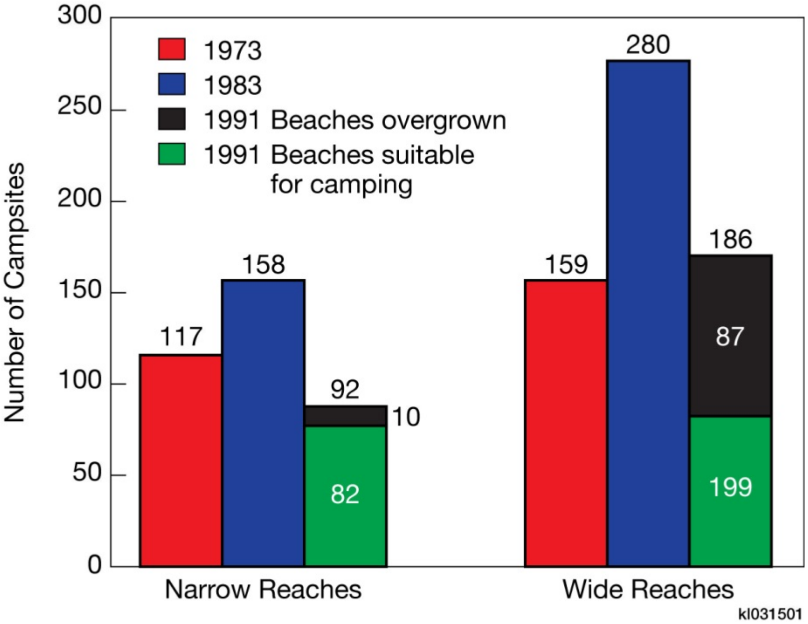

FIGURE 3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted in 1973, 1983, and 1991 (Source: Kearsley and Warren 1993)

sand area preferred by recreational campers has decreased by 55% since 1998, with an average rate of decline of about 15% per year (Kaplinski et al. 2005).

Debris fans continue to be replenished and enlarged by debris flows from tributaries. Thus, the formation of new rapids and the steepening of existing ones will continue in Marble and Grand Canyons. However, it has also been noted that the presence of the Glen Canyon Dam has greatly reduced both the magnitude and frequency of flood flows and, thereby, the capability of the river to move boulders from the rapids (Reclamation 1995). As a result, many debris fans may experience a buildup of boulders and an accumulation of smaller sediment particles (Melis and Webb 1993). Dam releases above powerplant capacity flows (i.e., >31,500 cfs) can partially rework debris-fan deposits, but this reworking is at a rate that is slower than the aggradation from tributary debris-flow deposits (Yanites et al. 2006). Pre- and post-MLFF flows have the same maximum potential release value (31,500 cfs); however, because MLFF has a maximum normal release value of 25,000 cfs and pre-MLFF had a maximum normal release of 31,500 cfs, the effect on debris flows of post-MLFF operations may be slightly less.

3.3.2 Sediment Characteristics and Transport Mechanisms

Sediment, especially as it occurs in sandbars along the Colorado River below Glen Canyon Dam, is an important and dynamic resource. The GCMRC has been focused on gathering sediment-related data, and understanding of important aspects of sediment science has evolved since the 1995 EIS (Reclamation 1995).

Glen Canyon Dam, completed in 1963, affects stream flow, sand supply, and sand transport in the Colorado River in Glen, Marble, and Grand Canyons. Historically, the Colorado River conveyed high suspended sediment concentrations throughout most seasons and had much larger flood flows and lower base flows (Schmidt and Grams 2011a). Because sediment sources for the Colorado River are not uniformly distributed in the Colorado Plateau, the placement of Glen Canyon Dam effectively cut off approximately 94% of the historical sediment supply from the upper watershed (Andrews 1991; Topping et al. 2000a; Wright et al. 2005). The conditions for sediment replenishment downstream of the dam are now imposed by the tributaries (e.g., Paria River and Little Colorado River), which contribute to the Colorado River downstream of the dam and affect the mechanisms that control sandbars in Glen, Marble, and Grand Canyons. Because of the dam, the capacity of the Colorado River to transport sand and other sediment in the Colorado River Ecosystem is reduced. Sediment transport in the Colorado River was already in decline in the pre-dam era as a result of changes in seasonal rainfall patterns, increased upstream diversions and dam construction, and the slowing of stream entrenchment (Howard and Dolan 1981). Maximum releases from the dam are substantially less than the historic annual peak flows. The high-water zone has been lowered to the level corresponding to managed releases as a result of the dam. These changed conditions have reduced the height of annual deposition and increased the rate of erosion of sediment (Reclamation 1995), and contributed to the loss of beaches and sandbars for many years. Figure 3.3-7 illustrates some of the common changes that have occurred from 1955 to 2008.

FIGURE 3.3-7 Repeated Photography Illustrating Sediment Losses and Sandbar Changes along the Colorado River (These photographs show a portion of the bank of the river in Grand Canyon, 150 mi downstream from the dam. View is downstream from the right (north) bank of the Colorado River. The top image [Source: USGS 2002], taken in 1952, shows a large sandbar. The middle image [Source: USGS 2002], taken in 1995, shows little remaining sand. The bottom image [Source: J. Schmidt, GCMRC], taken in June 2013, shows that some sand was deposited by the November 2012 HFE.)

The sediment resource goal for the LTEMP EIS is to increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the current average base flow for ecological, cultural, and recreational purposes. As a resource, the primary considerations for sediment relate to the spatial and temporal dynamics of sediment storage throughout the Colorado River below Glen Canyon Dam. The focus of this section is the sediment characteristics and transport mechanisms that interact with flow regimes dictated by releases from Glen Canyon Dam to govern erosional and depositional processes affecting sandbars. The processes that generate sandbars are linked to several factors, including particle size, sediment supply, flow velocity, channel geomorphology (described previously), and river stage, so it is necessary to consider all these factors when assessing impacts on sediment resources.

3.3.2.1 Particle Size and Sediment Supply

Sediments are typically classified by particle size, and they include the following classes:

- Silt and clay (<0.06 mm);
- Sand (0.06 mm–2.0 mm);
- Gravel and cobbles (2.0 mm–200 mm); and
- Boulders (>200 mm).

In general, the term “fine sediment” refers to sediments that are sand-sized or smaller. This group makes up the most abundant sediment size class found along the river, especially in GCNP below the Paria River. GCNRA has little to no fine sediment input and contains mostly coarse sediment until the river reaches its first major tributary, the Paria River. The majority of the sediment delivered to and transported by the Colorado River is defined as silt and clay, which are carried in suspension by most dam releases. The quantity of silt and clay transported depends mainly on tributary supply. Sandbars contain some silt and clay, but their existence primarily depends on the transport of sand.

Sand is stored throughout Glen and Grand Canyons in bars (or patches) on the riverbed, in eddies, and on terrace sandbars. Sandbars and terraces are used as campsites by boaters and are substrate for vegetation and wildlife habitat. The next-largest sizes are gravel and cobbles, which, together with small boulders, armor the streambed in some places. Certain fish species use shallow gravel beds for spawning. The largest particles are boulders, some larger than automobiles, which fall from the canyon walls or reach the river in debris flows from steep tributary canyons. Boulders create and modify most of the major rapids and are also a factor in the creation of sandbars. Although its riverbed is bedrock in some places, the Colorado River generally is a cobble- and gravel-bed stream through which sand is transported (Graf 1995).

3.3.2.2 Sediment Transport Capacity

The river's capacity to transport sediment increases non-linearly, as a power function of the volume of water flowing in the river. The turbulence of flowing water can increase the amount of sediment in suspension and available for transport. Once the weight of the sediment particles exceeds the suspension force from the water current, the sediment is deposited. The greater the river's flow, the greater its velocity; the greater the turbulence, the greater its sediment load-carrying capacity. Finer particles (i.e., clay and silt) are carried in suspension by nearly all dam releases. Flows in the river are often large enough to carry sand grains in suspension or roll them along the riverbed, temporarily depositing the grains in areas where water velocity is insufficient to move them. Higher flows and velocities are needed to move gravel and cobbles. The largest boulders remain in place for decades or more, awaiting a flood large enough to move them even short distances along the riverbed.

The amount of sand stored within the riverbed each year depends on the tributary sand supply (which is highly variable), the pattern of water released from the dam, and the amount of sand already deposited on the riverbed at the beginning of the year. Sand stored on the riverbed is the principal source for building sandbars during periods of high releases.[5]

3.3.2.3 River Stage

River stage defines the water level associated with a given discharge, which may be a result of both dam release and tributary inflow. Fluctuations in river stage are particularly important to cycles of deposition and erosion within sandbars. While fine sediments are readily transported by the Colorado River, the height of their deposition depends on river stage. Seepage-induced erosion is also affected by fluctuations in river stage because groundwater levels within exposed sandbars rise and fall with increases and decreases in river stage. When the river stage declines faster than groundwater can drain from the sandbar, the exposed bar-face becomes saturated, forming rills that move sand particles toward the river (Reclamation 1995; Alvarez and Schmeeckle 2013).

3.3.3 Sediment Sources

Sediments in the Colorado River are delivered by tributary streams and ephemeral washes. Although most of the water in the Colorado River originates in the Rocky Mountains, most of its sediment load originates from more arid regions in the interior of the river basin (Schmit and Schmidt 2011). In the post-dam era, the Colorado River is no longer the source of sediment to the river downstream of the dam. As a result of the closure of the Glen Canyon Dam,

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[5] In an average pre-dam year, sand in Marble Canyon and the upper Grand Canyon would accumulate during 9 months of low flow (July through March); higher flows in April through June (from spring snowmelt) would then erode and transport the stored sand. Since the closure of Glen Canyon Dam, there is no discernible seasonal pattern of accumulation in the Canyons (Topping et al. 2000a; Hazel et al. 2006).

the annual sediment supply past Lees Ferry dropped from a pre-dam level of around 57 million metric tons per year (MT/yr) to about 0.24 million MT/yr during the post-dam period from 1966 to 1970, a reduction in sediment supply at Lees Ferry of more than 99% (Topping et al. 2000a).

The Paria River, Little Colorado River, and nearly 800 smaller gaged and ungaged tributaries now serve as the primary sources of sediment to this reach of the river (Webb et al. 2000; Schmidt and Grams 2011a). Taken together, the contributions of sand from various sources provide the Grand Canyon with approximately 16% of its pre-dam sand levels (Wright et al. 2005). Mass balance sand budgets in the Colorado River below the dam vary within and among years, depending on the amount of tributary sediment input and the monthly volume releases from the dam. Because of this dynamic nature, it is only possible to provide an estimate of the relative sediment budget that is representative of the river channel. In general, the lesser tributaries in the upper Marble Canyon upstream of RM 30 together contribute roughly 10% of the amount of sand annually supplied by the Paria River; downstream from RM 30, the lesser tributaries supply negligible amounts of sand (Griffiths and Topping 2015). However, the sediment inputs from these tributaries appear to be decreasing over time (see the following sections for further details related to gaged and ungaged tributary sediment inputs). Sediment supply is one of the important uncertainties related to managing this resource.

Debris flows have been documented in nearly 740 tributaries in the Marble and Grand Canyons between Lees Ferry and Diamond Creek; tributaries between the dam and Lees Ferry were found to produce only stream flow (Webb et al. 2000). Debris flows tend to be high-magnitude, short-duration events. Debris flows create and maintain the rapids (i.e., hydraulic controls), control the size and location of eddies, and serve as potential sources of sand to replenish sandbars of the Colorado River in the Marble and Grand Canyons.

The coarse sediments associated with debris-fan deposits can only be mobilized during flood flows and do not constitute a significant contribution to sediment loads transported by the river. However, their dynamics are important with respect to their retention of fine sediments and the development of geomorphic structures (e.g., fan-eddy complexes). While it has been predicted that the reduction in flood flows caused by Glen Canyon Dam could result in a greater accumulation of coarse sediment on debris fans, it has been shown that flood flows during the post-dam era also have the potential to transport coarse sediments from debris flows and eroding sandbars (Schmidt and Grams 2011a).

The occurrence and size of both debris flows and flash floods are influenced by geologic and geomorphic conditions within the watershed (see Section 3.3.1.1 for more detail on the geomorphic features of the Colorado River within the project area). They are also affected by the prior history of flows and the amount and intensity of precipitation. For example, Havasu Creek has not had a debris flow in recent geologic time, but it had an enormously destructive flash flood in September 1990. In general, slope failures in the steep tributary valleys commonly trigger debris flows; however, the geologic conditions favorable for debris flows from side canyons vary greatly throughout the area. Therefore, the potential for sand delivery from these tributaries to the mainstem Colorado River also varies throughout the canyon (Webb et al. 2000).

3.3.3.1 Gaged Tributaries

The two largest sediment-contributing tributaries to the Colorado River downstream of the Glen Canyon Dam are the Little Colorado River and Paria River. Sand contribution from the Paria and Little Colorado Rivers, estimated at USGS gaging stations, varies greatly from year to year (see Figure 3.3-8). Together, these two tributaries supplied about 10 to 15% of the total sand load in the pre-dam era (Topping et al. 2000a). Today, they are the two principal suppliers of sand to the Colorado River downstream of the dam through the project area.

The amount of sediment supplied by the Paria River is one of the highest among watersheds on the Colorado Plateau. From 1997 to 2014, the mean annual load has been estimated to be about 2.24 million MT/yr (GCMRC 2015a). Long-term records of sand inputs for the Paria River have suggested that approximately 75% of the average sand supply is delivered during the summer and fall when monsoonal storms are most likely to erode hill slopes in the upper basin and carry more fine sediments (Topping et al. 2010; Wright and Kennedy 2011). The historical median diameter of Paria River sand is approximately 0.13 mm; based on more recent data from 1994 to 2000, about 92% of the influx of sand from the Paria River is finer than 0.25 mm (Topping 1997; Hazel et al. 2006).

The annual average sediment load for the Little Colorado River, using data from 1994 and 2009, has been estimated to be about 4.34 million MT/year, of which approximately 30 to 40% was sand (GCMRC 2015a). Research from the mid-1980s through the early 2000s showed that the Little Colorado River contributed substantially less sand than the Paria River over a decadal time scale, despite the fact that the Little Colorado River basin is nearly 18 times larger than the Paria River basin (Wright et al. 2005; Rubin et al. 2002). These differences in sediment supply could be related to differences in watershed characteristics, including water loss (infiltration) in dryland channels in the increasingly arid climate within the Little Colorado River watershed (Block and Redsteer 2011) and the presence of multiple small dams or impoundments in the Little Colorado River drainage.

3.3.3.2 Ungaged Tributaries

Sediment supplied by the numerous small ungaged tributaries along the Colorado River is much more difficult to estimate because there are no stream gages. Studies have attempted to calculate sediment loads from ungaged tributaries using a number of methods, including mass-balance calculations assuming quasi-equilibrium, regional sediment-yield equations, sediment-rating curves, and peak discharge to total sediment-load relations (Griffiths and Topping 2015). However, there has been some scientific debate over these methods and over the resulting estimates from these various sources (Griffiths and Topping 2015; Schmidt and Grams 2011a). As a result, eight new gages were established in the late 2000s on previously ungaged lesser tributaries in Glen, Marble, and Grand Canyons to better estimate the supply of fine sediment (sand, silt, and clay) from these tributaries to the Colorado River (Griffiths and Topping 2015). Over the 13-year study period, the annual sediment load from the lesser tributaries to the Colorado River in upper Marble Canyon was found to vary two orders of magnitude, from approximately 1,800 to 340,000 metric tons of sand and around 2,900 to 370,000 metric tons of

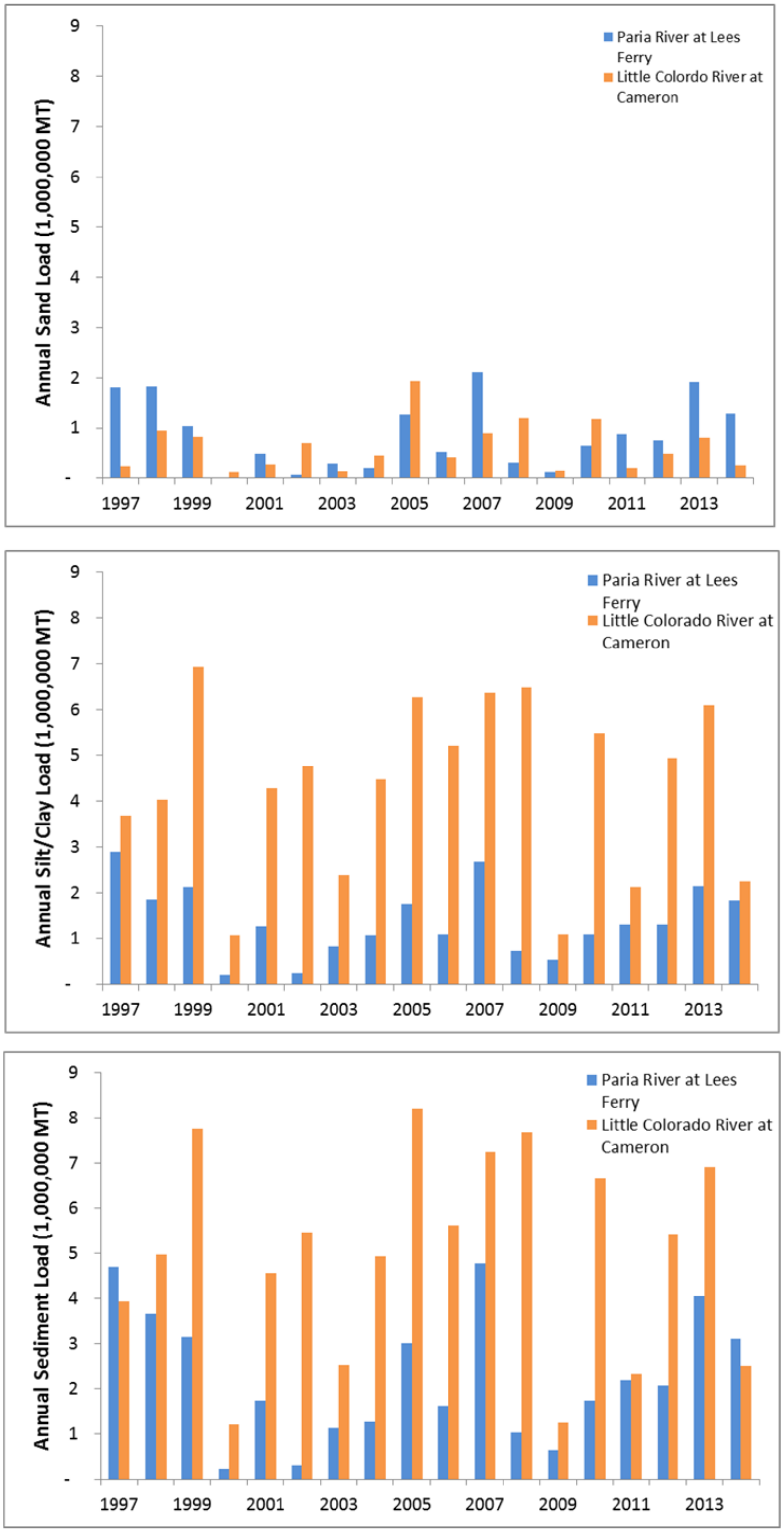

FIGURE 3.3-8 Annual Sediment Contributions from the Paria and Little Colorado Rivers (Source: GCMRC 2015a)

silt and clay. This is equivalent to about 10% of the measured mean annual sand load and about 8% of the measured mean annual silt and clay load in the Paria River. The annual sand load of the lesser tributaries ranged from1.6 to 49% of the annual sand load of the Paria River during individual years. The measured mean-annual silt-and-clay load translates to about 8% of that in the Paria River over the same period (Griffiths and Topping 2015).

Results from the more recent sediment-monitoring network also found that sediment loads do not necessarily correlate with drainage size, and cumulative sediment loads may vary by two orders of magnitude on an annual basis. Thus, previous indirect estimates of annual sediment load from the tributaries were generally too high; this translates to a sediment budget for the Colorado River below Glen Canyon Dam that is in greater deficit than previously concluded by most researchers (Griffiths and Topping 2015).

3.3.4 Sediment Transport and Storage

The operations of Glen Canyon Dam that affect sediment resources can be generally categorized as either operational flows (e.g., daily, monthly, and seasonal) or experimental releases (i.e., HFEs, described in more detail below). Using different flow regimens to manage sediment resources involves establishing a balance between erosional and depositional processes, which is controlled by many factors, including sediment sources and characteristics (described above), as well as physical aspects of sediment transport and storage (described below), that control the sediment balance. However, many uncertainties still remain regarding how these factors influence erosion and depositional processes, which generate the spatial and temporal variations in sandbar and channel-margin deposits throughout the Colorado River (Schmit and Schmidt 2011).

3.3.4.1 Sediment Transport

The term “sediment load” refers to sediment being transported by the river. Sediment load is further categorized as either bedload (i.e., particles moving along the river bottom) or suspended sediments (i.e., particles in the water column). More than 90% of the sand transported through the Colorado River system is considered suspended load (Schmidt and Grams 2011b). Sediment transport is controlled by a balance of forces (shear stress, drag, buoyancy, and gravity) acting on sediment particles, where the force balance is further controlled by properties of the flow, river geomorphology, and the surface area, concentration, density, size, and shape of the sediment particles available for transport.

A mass balance approach is commonly used to quantify sediment transport. Mass balance is calculated as the mass of sediment within a reach of the river relative to the amount of sand transported into and out of the reach. A positive mass balance indicates that more sediment is transported into the reach than out of the reach, and a negative balance indicates that more sediment is transported out of the reach than into the reach. Theoretical and empirical formulations that quantify sediment transport are described in more detail in Appendix E.

3.3.4.2 Sediment Storage

Sediment deposits at rest on the riverbed, within sandbars, and along channel margins represent the sediment storage of a river. Sediment storage is the result of coupled flow, sediment transport, and geomorphological conditions (e.g., low-energy recirculating flow within fan-eddy complexes) that result in deposition of sediments. It is important to note that sediment storage does not necessarily mean that there is no movement; instead, it refers to the net condition (i.e., mass balance) between sediment deposition and erosion at a point of interest over a specified period of time. Thus, sediment storage is a dynamic condition that varies based on the specific spatial and temporal scales considered; it can be increasing (net deposition), decreasing (net erosion), or at equilibrium. For example, the net sediment mass balance for a river reach may be in equilibrium over a year-long period. However, on a finer geographic scale, an individual bar may actually be aggrading or eroding as it exchanges sediment with another location within a reach. On a finer temporal scale, seasonal variation over the year-long period would also become apparent.

It has been estimated that more than 80% of the post-dam fine sediment in the Marble Canyon reach is stored in eddies below the 8,000-cfs stage (Hazel et al. 2006). However, deposition above this stage determines the amount of sand that can be seen and used by visitors to GCNP and how much sand is potentially available for campsites (Schmidt and Grams 2011b). Research has also shown that sand supplied from unregulated tributaries remains in storage for only a few months before most of it is transported downstream, unless flows are below approximately 9,000 cfs (Topping, Rubin, et al. 2000a; Rubin et al. 2002; Schmidt and Grams 2011b).

3.3.4.3 High-Flow Experiments

The Glen Canyon Dam Adaptive Management Program (GCDAMP) has conducted six HFEs (the first was called a Beach Habitat Building Flow), which occurred in 1996,[6] 2004, 2008, 2012, 2013, and 2014, to study the controlling factors that act together to build and maintain sandbars. The primary goal of an HFE is to rework sediments contributed by the Paria River, the Little Colorado River, and ungaged tributaries from the riverbed up to sandbar features that are at elevations above operational flow stages (Schmidt and Grams 2011b; Wright and Kennedy 2011; Reclamation 2011d). The first three HFEs conducted have been extensively studied and reported on (Melis 2011; Melis et al. 2011). Overall, these types of sediment-enriched flows were found to be effective at building sandbars (see Figure 3.3-9 as an example), although post-HFE erosion of sandbars did occur at varying rates depending on flow conditions (Wright and Kennedy 2011). More importantly, the research on these early HFEs highlighted the need to study the cumulative effects of more frequent HFEs and motivated Reclamation to

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[6] Although the purpose of the 1996 HFE was to control nearshore vegetation and remove nonnative fish downstream of Lees Ferry, the experiment also yielded important information on sediment deposition on sandbars (Schmidt and Grams 2011a). It differed in many significant ways from later HFEs including that it was not sediment-triggered and was much longer in duration.

develop an HFE protocol (Reclamation 2011d) that outlines conditions for implementing HFEs. The protocol also provides a methodology for determining the timing, magnitude, and duration of an experimental HFE (Russell and Huang 2010; Reclamation 2011d). The subsequent 2012, 2013, and 2014 HFEs were a direct result of this protocol.

In general, high flows with low suspended sediment concentrations have greater erosive potential, while high flows with high suspended sediment concentrations generate a greater potential for deposition (Topping et al. 2010). Thus, the primary mechanism for building sandbars seems to involve flood events that can mobilize and rework sediments from the tributary inputs and riverbed and deposit them at a high-flow stage in fan-eddy complexes and channel-margin areas. However, several factors affect both the efficiency with which a flood event can build sandbars and the spatial variability of the sandbar response.

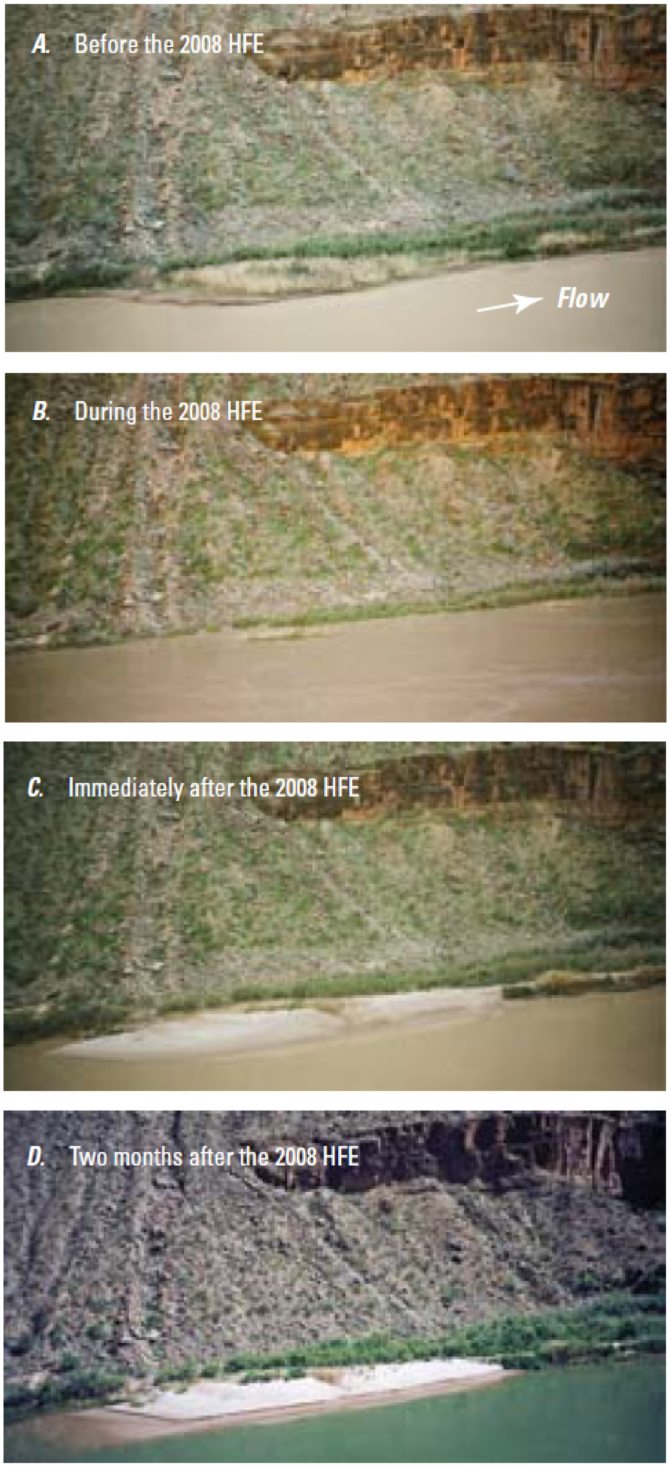

FIGURE 3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to the 2008 HFE (Source: Schmidt and Grams 2011b)

Preliminary results indicate that sandbar building occurred in Marble and Grand Canyons during each of the fall HFEs conducted from 2012–2014. Sandbars were larger following each HFE at more than half of the 45 long-term monitoring sites (Grams et al. 2015). Immediately following the 2012, 2013, and 2014 HFEs, sandbars were larger at 52%, 52%, and 57% of the monitoring sites, respectively (Grams 2016). Sandbar size did not change substantially at 35% of the monitoring sites following each of the same HFEs. The most recent topographic surveys completed in fall 2015 indicate the total volume of sand with the long-term monitoring sandbars increased during the first 4 years of implementation of the HFE protocol (Grams 2016). Preliminary results also indicate that each of these later HFEs evacuated less sand from upper

Marble Canyon than had been delivered there in the immediately preceding fall accounting season (Schmidt 2015). The net effect of less sand being evacuated by each HFE in relation to each year's sand delivery from tributaries has led to progressive sand accumulation in upper and lower Marble Canyon (Schmidt 2015).

3.3.4.4 Sediment Supply Limitation

In general, flow hydraulics and sediment particle sizes, in addition to the presence of critical geomorphic features (e.g., fan-eddy complexes), appear to be the primary factors controlling sandbar deposition (Topping et al. 2010). Thus, an HFE needs to have high velocities and turbulence, coupled with ample fine sediment supplies in the main channel, to increase suspended sediment concentrations. However, it is difficult to predict the sediment transport and storage in the Colorado River in response to HFEs, primarily because the quantity and particle size distributions of sediment available for transport are not consistent throughout a flood hydrograph, between floods, or over the length of the river (Schmidt and Grams 2011a).

Sediment supply limitations can affect the physical processes that govern sediment deposition during HFEs. It is necessary to have a higher concentration of suspended sediments in the main channel to ensure deposition in the fan-eddy complex (Rubin et al. 1998). Conversely, when suspended sediment concentrations are higher in the fan-eddy complex than in the main channel, there exists the potential to erode sand from the fan-eddy complex. During the early stages of an HFE, the finer-grained components are preferentially entrained from the riverbed and transported; consequently, the early sandbar deposits during a high flow are dominated by finer-grained sand. Once the finer-grained sand is winnowed from the riverbed, the suspended sand concentration decreases and the sand in suspension becomes coarser-grained.

3.3.4.5 Sandbar Deposition and Retention

Sandbars experience cycles of deposition and erosion during normal dam operations. Generally, net erosion is a result of turbulent exchange, decreases with distance downstream of the dam, and increase with daily fluctuations in stage. Sandbar erosion can also result from nearshore currents, waves generated by rapids, seepage erosion caused by dewatering sandbars and groundwater flow, wind, tributary floods, and hillslope runoff (Alvarez and Schmeeckle 2013; Schmidt and Grams 2011a; Melis et al. 1995; Budhu and Gobin 1994; Bauer and Schmidt 1993). Sandbar deposition requires high flows and adequate sediment supply. Without occasional periods of sustained high releases (i.e., above powerplant capacity), sandbars, particularly those at high elevation, will eventually erode and not rebuild (Andrews 1991; Schmidt and Grams 2011a).

Long-term rehabilitation of eddy sandbars can occur only if the increases in sand volume caused by high flows exceed the erosion that occurs during the intervening periods. Alternatively, if there are only small amounts of deposition during high flows and large volumes of erosion during intervening periods, a long-term decrease in sandbar size will result. Figure 3.3-10 presents a conceptual diagram illustrating the dependency of net sandbar size on

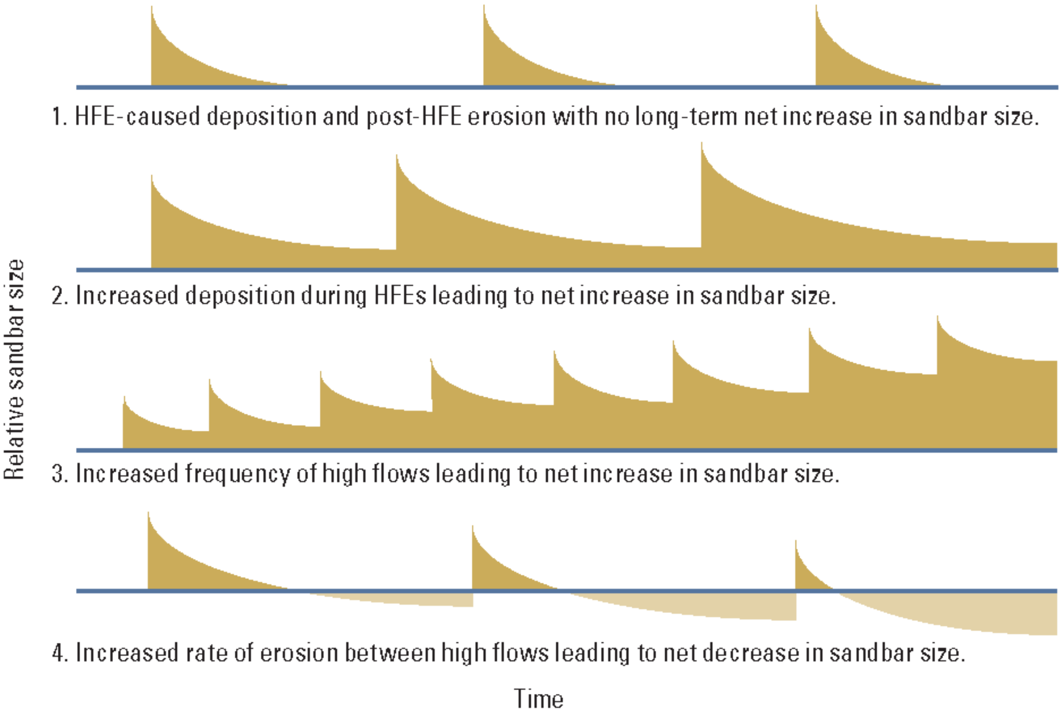

FIGURE 3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size, Duration and Frequency of HFEs, and Post-HFE Erosion Rates (Source: Schmidt and Grams 2011a)

potential variations during a series of hypothetical HFEs in the amount of deposition, frequency of HFEs, and rate of post-HFE erosion. The first graph shows HFE deposition followed by an equal amount of erosion. The second and third result in net increases in sandbar size by increasing the amount of deposition during HFEs and increasing the frequency of HFEs, respectively; this would require sufficiently great antecedent sand enrichment to support either larger or more frequent HFEs. The last graph depicts a higher rate of erosion following the HFEs, resulting in net decreases in sandbar size (Schmidt and Grams 2011b).

In each of the HFEs,[7] the majority of sandbars exhibited net deposition, as illustrated by the data presented in Figure 3.3-11. The highest level of eddy-sandbar deposition above the reference stage was observed in the parts of Marble and Grand Canyons where the suspended-sand concentration was greatest (Schmidt and Grams 2011b). It is also important to note that, conversely, between 14 and 18% of the monitored sandbars exhibited net erosion (Schmidt and Grams 2011b). Overall, the 1996 HFE (previously referred to as a Beach Habitat Building Flow) resulted in more sandbar erosion than was expected, and antecedent sediment conditions

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[7] Summary sandbar results presented are for the 1996, 2004, and 2008 HFEs. The 2012, 2013, and 2014 HFEs post-date the referenced report. Findings from the later HFEs will be released by GCMRC once the research is complete (GCMRC 2014).

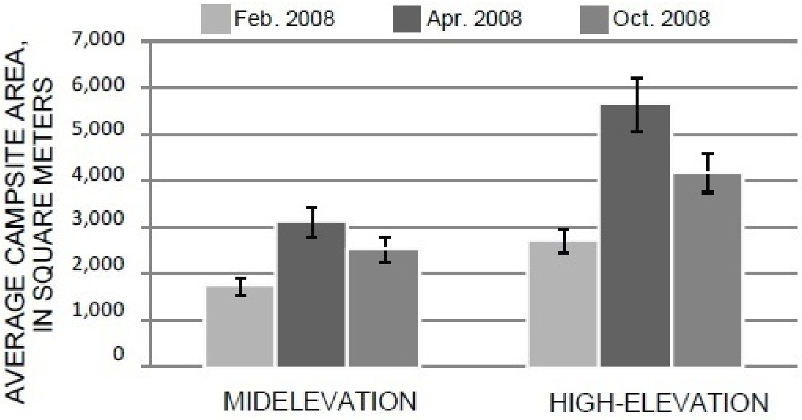

FIGURE 3.3-11 Average Campsite Area above the References Stage: before, after, and 6 Months following the 2008 HFE (Source: Hazel et al. 2010)

(pre-HFE tributary inputs and analyses of sediment storage) were determined to be limiting with respect to sediment storage in the system. As a result, subsequent HFEs were all performed under more enriched sediment conditions, because it was assumed that increased sand enrichment volumes would yield increased suspended sediment loads and higher volume deposits. However, analysis of data from the 2004 and 2008 HFEs suggested that this assumption was not necessarily true. Greater levels of sand enrichment will lead to greater reach-averaged bed-sand area, but will not always lead to finer reach-averaged bed-sand grain size. Thus, both grain size and magnitude of sand supply need to be considered in order to maximize sandbar deposition (Topping et al. 2010).

In the period after each of the HFEs, sandbars tended to erode. In general, sandbar erosion rates were especially high immediately following each of the HFEs, then continued at a slower rate (Schmidt and Grams 2011b). The pattern of net erosion after the HFEs mirrors the changes that occurred during flooding. That is, the pattern of high-elevation deposition and low-elevation erosion is dominant during high-flow, high-elevation erosion, and low-elevation deposition is the dominant pattern during intervening low flows (Hazel et al. 2006).

Overall, research suggests that the HFEs are effective at temporarily building the area and volume of sandbars in fan-eddy complexes. However, long-term rehabilitation of sandbars is only possible if the increases in sand volume caused by the HFEs exceed the erosion during intervening operational flow periods (Schmidt and Grams 2011b) (see Figure 3.3-10). Furthermore, net storage gains in the sandbars as a whole cannot occur if sand is simply being transferred from one bar to another during an HFE. The current state of knowledge suggests that modifying the base flow regime alone (flows below 31,500 cfs and without the use of HFEs) cannot increase the area and volume of sandbars over annual or multi-year timescales (Topping et al. 2010). High flows are needed to get the water surface high enough to deposit sand at higher elevations. Therefore, the research suggests that both the number of HFEs and the base flow regime are factors that affect the building and retention of sandbars.

3.3.5 Lake Deltas

Sedimentation rates among reservoirs are highly variable, due mainly to regional climatic and geomorphic differences that affect sediment delivery. In general, the coarser particles (i.e., mostly sand) carried into the reservoirs by tributaries are deposited as deltas in the tributaries arm. The majority of finer particles (i.e., silt and clay) are carried farther downstream into the reservoir, where they settle out as lakebed deposits. Deltas fill the upstream parts of the tributary arms first, building toward the submerged mainstem channel and eventually the dam. Some sediment deposited in upstream parts of the delta may be transported downstream as a result of flood flow when the reservoir is low. The upper surfaces of deltas function as important substrate for vegetation and riparian habitat and can affect recreational navigation and the water quality of the reservoir (Reclamation 1995).

The characteristics of a delta depend on variables such as the quantity and size of inflowing sediment, dam operations, surface water elevation, and hydraulics in the tributary arms. Other factors include erosion and vegetative growth along the margins of the tributary arms and turbulence and density currents in the reservoir. The longitudinal profile of a delta depends primarily on reservoir levels and the slope of the channel through the delta (Strand and Pemberton 1982; Reclamation 1995).

The live storage capacity of Lake Mead is 26.399 maf at an elevation of 1,221.4 ft. All sediment transported into Lake Mead by the Colorado River and its tributaries is trapped in deltas and lakebed deposits. Before closure of Glen Canyon Dam, the total upstream drainage area contributing sediment to Lake Mead was 171, 500 mi^2. Since the dam's closure in 1963, sediment contribution upstream of Lake Powell has been essentially cut off. As a result, the drainage area that could contribute sediment above Lake Mead has been reduced by an estimated 65%, or approximately 59,800 mi^2 (Ferrari 2008). Additional information on the hydrology and water quality of Lake Mead is presented in Sections 3.2.1.3 and 3.2.2.3, along with a map of the reservoir and vicinity (Figure 3.2-2).

Longitudinal profiles of the mainstem Colorado Riverbed elevation upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 are illustrated in Figure 3.3-12. In general, the location along the river where the Colorado River intersects Lake Mead depends greatly on the reservoir's water level elevation, which is primarily controlled by the combination of releases from the Glen Canyon and Hoover Dams. The maximum recorded riverbed elevation was 1,220 ft, which roughly corresponds to the elevation of the riverbed downstream of Bridge Canyon (RM 235) in Lower Granite Gorge. Thus, RM 236 is the approximate upper end of the Colorado River delta, which extends past Pierce basin to about RM 290 (Reclamation 1995).

The shape of the Colorado River delta profile is also affected greatly by reservoir elevation. The delta surface in lower Granite Gorge and upper Lake Mead is relatively flat and composed mainly of sand, which begins to drop out of suspension at the point where the river meets the reservoir (as noted above). Beyond the delta, river and reservoir currents can carry large volumes of finer sediment farther into Lake Mead. Lakebed sediments consist of predominantly fine sediments: 60% clay, 28% silt, and 12% sand. Lakebed deposits extend all the way to Hoover Dam at RM 355, even though the longitudinal profile dips steeply at the delta

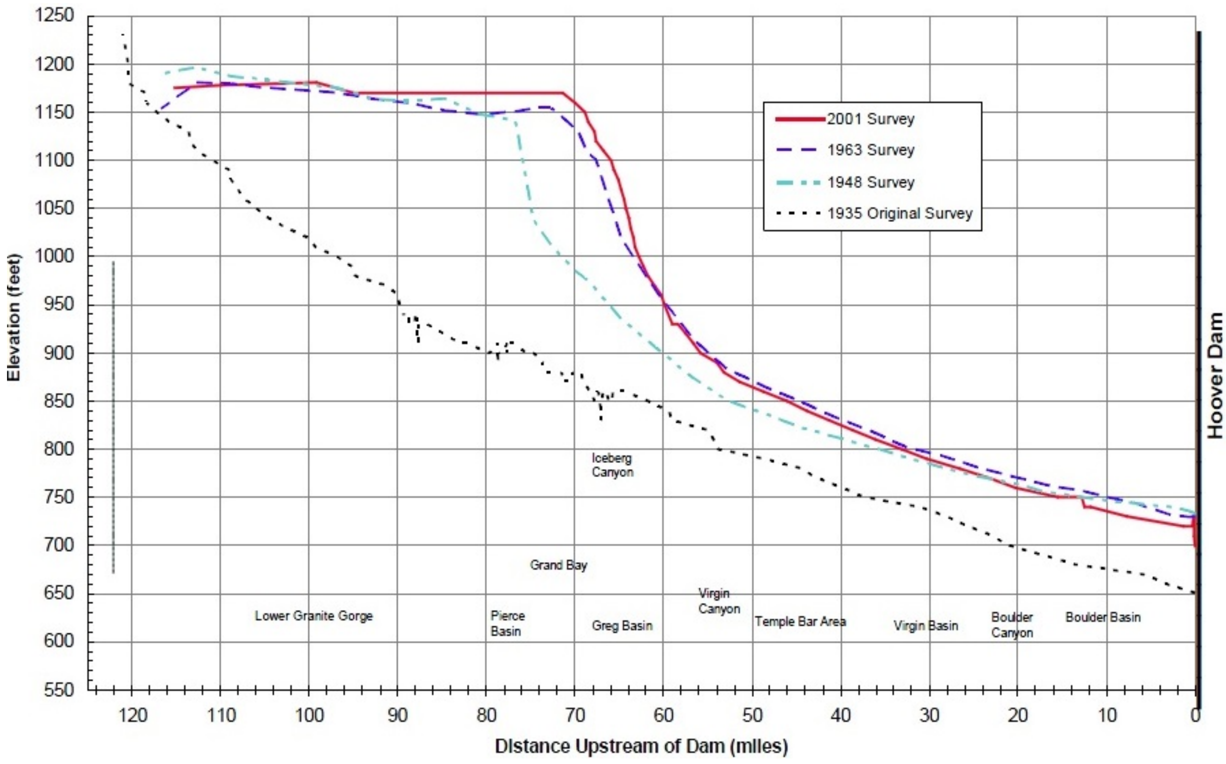

FIGURE 3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 (Source: Ferrari 2008)

crest. The elevation of the delta crest, where the slope changes from relatively flat to relatively steep, has migrated over time (see Figure 3.3-12). According to the 1948–1949 survey of the delta, the delta crest was at RM 278; by the time of the 1963–1964 survey, it had progressed to RM 286 (Reclamation 1995). As of 2001, the delta had progressed another 2 to 3 mi lakeward. The recreational impacts of sediment accumulation in the lower reaches of the western Grand Canyon are described in Sections 3.10.2 and 4.10.2.6.

3.4 NATURAL PROCESSES

The Colorado River Ecosystem is defined as the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. An important objective of management of the Colorado River Ecosystem is the ability to sustain healthy populations of native plants and animals and natural ecological processes. NPS management policies state that (1) "whenever possible, natural processes will be relied upon to maintain native plants and animals and influence natural fluctuations in populations of these species" and (2) "the Service … will try to maintain all components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2006b). For the LTEMP, the natural processes resource goal is to "restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems." It is not possible to operate Glen Canyon Dam in a manner that could fully restore natural processes and their drivers to those that occurred under unregulated conditions due to, among other things, the existence of the dam and laws governing conveyance of water between the Upper and Lower Colorado River Basins.

Major drivers of natural processes in river ecosystems, including regulated rivers below dams, are river flow, water temperature, sediment transport, and water quality (including nutrients and turbidity) (Poff et al. 1997; Olden and Naiman 2010; Jones 2013a). These drivers directly and/or indirectly determine the abundance, condition, and status of native and nonnative plants and animals and their habitats in the ecosystem below a dam. The primary effects of dam operations on native plant and animal species and their habitats below the dam are a direct function of (1) the physical conditions (e.g., sediment transport, water temperature) that occur below a dam under specific operations; (2) how those conditions affect habitat quality, quantity, and stability; and (3) how aquatic and terrestrial biota will respond to those changes.

The construction and operation of Glen Canyon Dam has altered the ecosystem both above and below the dam (e.g., Turner and Karpiscak 1980; Brown and Johnson 1988; Carothers and Brown 1991; Blinn et al. 1992; Gloss and Coggins 2005; Kennedy and Ralston 2011; Cross et al. 2013). Before the dam, the river was sediment rich, transporting large quantities of sediment during spring and early summer and during flood events. Prior to construction of the dam, there was considerable seasonal and annual variability in flow and water temperature. Annual peak discharge typically reached between 85,000 and 120,000 cfs with records of 300,000 cfs, while flows in late summer, fall, and winter could be less than 3,000 cfs (Wright et al. 2005; Webb et al. 2005; Vernieu et al. 2005). Water temperatures fluctuated seasonally between 0°C (32°F) and 30°C (86°F), with highest water temperatures occurring in summer.

The physical changes that have resulted from dam construction and operation include serving as a barrier to the movement of most aquatic organisms between the Upper and Lower Colorado River Basins, a decrease in mean main channel water temperatures, a reduction in sediment supply and transport, increased bed scouring and incision, a reduction in peak flows with coupled reductions in the height of annual sediment deposition and areas of sediment erosion, increased daily fluctuations in flow and stage, and increased water clarity (Reclamation 1995; Topping et al. 2000a, 2003; Grams et al. 2007). Following completion of the dam, operations resulted in lower maximum annual volumes, lower peak flows, higher base flows, and decreased annual flow variability (Topping et al. 2003). In addition, in order to increase the value of hydropower, daily fluctuations increased, at times varying from 5,000 to 30,000 cfs (Wright et al. 2005). The incoming sediment load is deposited in Lake Powell and water released from the dam is clear. As a consequence, there has been a significant reduction in sediment supply and transport in the main channel below the dam (Topping et al. 2000a; Vernieu et al. 2005; Wright et al. 2005). Because of the location of the penstocks, water released from the dam is cold, averaging between 9 and 12°C (48° and 54° F), with warmest river temperatures occurring in late fall (Vernieu et al. 2005). Downstream water temperatures are more naturalized and exhibit greater variation, ranging from about 9°C (48°F) to 18°C (64°F) in the western Grand Canyon near Diamond Creek.

The presence of the dam and dam operations has resulted in changes in flow, sediment transport, connectivity, and water temperature. These physical changes, in turn, have resulted in an increase in nonnative riparian vegetation, changes in the distribution and composition of riparian vegetation communities, changes in the aquatic food base, the loss or reduction of native fish, and increases in nonnative fishes (Valdez and Carothers 1998; Gloss and Coggins 2005; Ralston 2005). The physical changes have resulted in a downslope migration of riparian vegetation toward the river's edge (Reclamation 1995; Sankey et al. 2015), the establishment of marshes in the varial zone (Stevens et al. 1995), the development of a cold-water zone that supports rainbow trout (McKinney, Speas et al. 2001; Reclamation 2011e), changes in the composition and productivity of the aquatic food base (Kennedy and Gloss 2005), and a restriction in the distribution, reproduction, and growth of native fish in locations downstream of the dam and tributaries (Gloss and Coggins 2005).

The status of physical conditions in the river is described in Section 3.2 (Water Resources) and Section 3.3 (Sediment Resources). These sections describe the past and current conditions associated with hydrology and flow, water quality (including temperature), and sediment transport and storage. Descriptions of biological resources in the system may be found in Sections 3.5.1 (Aquatic Food Base), 3.5.2 (Native Fish), 3.5.3 (Nonnative Fish), 3.6 (Vegetation), and 3.7 (Wildlife).

3.5 AQUATIC ECOLOGY

This section presents information on the aquatic ecology of the Colorado River between Glen Canyon Dam and the inflow of Lake Mead. Included are discussions of the aquatic food base (i.e., invertebrates, algae, rooted plants, and organic matter that serve as the base of the food web for fish; Section 3.5.1), native fish (including endangered and other special status species; Section 3.5.2), and nonnative fish (including coldwater and warmwater species; Section 3.5.3). For all of these topics, the effects of dam operations and other factors on these resources are discussed.

3.5.1 Aquatic Food Base

Invertebrates (animals without backbones), algae, rooted plants, and organic matter serve as the aquatic food base for fishes in the Colorado River Ecosystem (Gloss et al. 2005). Although most of this food base is produced within the aquatic system, terrestrial inputs to the Colorado River Ecosystem of organic matter (e.g., leaf litter) and invertebrates also contribute. In turn, instream production of both algae and invertebrates helps support terrestrial consumers such as grasshoppers and spiders, insectivorous birds and bats, reptiles, and waterfowl; indirect links include peregrine falcons, belted kingfishers, osprey, great blue herons, and bald eagles, which feed on fishes or waterfowl that consume aquatic food base organisms (Bastow et al. 2002; Baxter et al. 2005; Sabo and Power 2002; Shannon, Kloeppel et al. 2003; Shannon et al. 2004;

Stevens and Waring 1986a; Yard et al. 2004). See Section 3.7 of this EIS for a discussion of riparian and terrestrial wildlife. Flow patterns and temperature (all of which were and continue to be influenced by the presence and changing operations of Glen Canyon Dam) have a major influence on the food base of the Colorado River Ecosystem within the Grand Canyon.

This section presents an overview of the aquatic food base prior to and following the construction and operation of Glen Canyon Dam. Included in the discussion are invasive aquatic species that have affected or may affect food base organisms of the Colorado River downstream of Glen Canyon Dam. The major groups of aquatic food base organisms include (1) periphyton (e.g., algae and cyanobacteria that live attached to rocks and other surfaces) and rooted aquatic plants, (2) plankton (very small plants [phytoplankton] and animals [zooplankton] that occur in the water column), and (3) macroinvertebrates (i.e., invertebrates that are visible to the naked eye).

As summarized by Cross et al. (2013), large dams alter the physical template of rivers by changing flow, temperature, and sediment regimes. Nutrients and sediments are trapped in reservoirs such as Lake Powell rather than being carried downstream (Johnson and Carothers 1987). These changes alter riverine food webs, reduce biodiversity, and often lead to extirpation of native species and facilitation of invasion by nonnative species.

Prior to the construction of Glen Canyon Dam, the productivity of the Colorado River was low due to scouring by annual floods and high turbidity, although there were productive areas in rapids, riffles, whirlpools, and backwaters (Woodbury 1959; Haden et al. 2003). Collections made along the banks of the Colorado River in Glen Canyon and in tributaries or side canyons included 28 species of green algae, 5 species of cyanobacteria, 20 species of diatoms, and 91 species of aquatic insects (e.g., mayflies, dragonflies, true bugs, dobsonflies, caddisflies, aquatic moths, beetles, and true flies). Only 16 insect species were collected from sites along the river in Glen Canyon (including 4 species of mayflies and 3 species of caddisflies), while 77 species were collected from tributaries. Examination of fish stomach contents indicated that organisms derived from tributaries and terrestrial habitats played an important part in the diet of river fishes in Glen Canyon (Woodbury 1959).

The combination of altered flows, reduced organic inputs from areas upstream of the dam, decreased turbidity, and an altered thermal regime has led to a shift in the aquatic food base in the Colorado River below Glen Canyon Dam (Benenati et al. 2002; Blinn et al. 1995; Kennedy and Gloss 2005). In general, aquatic invertebrate diversity has declined, while density and biomass have increased (Kennedy and Gloss 2005). The influence of Glen Canyon Dam, coupled with sediment inputs from tributary streams, has resulted in a stair-step decrease in the food base biomass in the Colorado River. In the post-dam period, the 16-mi reach of Glen Canyon accounted for 69% of the algal and 50% of the macroinvertebrate mass collected throughout the 224-mi section of the Colorado River. Sites within Marble and Grand Canyons contributed 18 and 41% and 13 and 9%, respectively, of algal and macroinvertebrate biomass. Food base reductions in reaches downstream of the Paria River result from elevated sediment inputs from tributary streams. The suspended sediments increase turbidity and the deposited sediments alter substrate characteristics (Shannon et al. 1994, 2001). Thus, the aquatic food base of the tailwater section (between the dam and the Paria River) and the rest of the mainstem (e.g., between the Paria River and Diamond Creek) are often discussed separately. The Colorado River below the Paria River is seasonally influenced by tributary sediment and organic matter inputs, making them more similar to the pre-dam condition, particularly as distance from the dam increases (Rosi-Marshall et al. 2010).

Glen Canyon Dam operations have played a significant role in the formation of the varial zone (i.e., the portion of the river bottom that is alternately flooded and dewatered during operations, often on a daily basis). Benthic communities subject to periodic stranding, desiccation, ultraviolet radiation, and winter freezing often have depleted species diversity, density, and/or biomass in the varial zone (Fisher and LaVoy 1972; Hardwick et al. 1992; Blinn et al. 1995; Stevens, Shannon, et al. 1997).Recent studies have demonstrated that this varial zone actually constrains the abundance and diversity of aquatic insects in the Colorado River downstream of Glen Canyon Dam (Kennedy et al. 2016), thereby limiting the amount of invertebrate prey that is available to support native and desired nonnative fish populations. Most aquatic insects have complex life cycles with a winged adult stage that is terrestrial, while egg, larval, and pupal stages are aquatic. The majority of adult aquatic insects (~80%; Kennedy et al. 2016) use river edge habitats for egg laying, whereby eggs are cemented onto rocks or vegetation along the river edge and just under the water surface. Brief desiccation of insect eggs (e.g., 1 hour), as is typical of eggs laid in the varial zone, leads to their complete mortality (Kennedy et al. 2016). Evidence for this egg mortality effect can be seen throughout Grand Canyon, with aquatic insects being more abundant in locations where the timing of daily low flows coincides with peak egg laying activity (i.e., late afternoon), because insect eggs laid in these locations are never subjected to desiccation induced mortality. Additional evidence for this egg mortality effect is seen by comparing insect diversity downstream of dams throughout the Western United States, with insect diversity being strongly and negatively related to the degree of hydropower production (Kennedy et al. 2016). Thus, the varial zone downstream of hydropower dams, such as Glen Canyon, greatly reduces the quality and availability of river edge habitats that are used by aquatic insects for their egg laying; this constrains both the diversity and abundance of aquatic insects that are present in these ecosystems.

More detailed information on the effects of dam operations on the aquatic food base is provided in Section 4.5.

3.5.1.1 Periphyton and Rooted Aquatic Plants

Physical factors associated with dam releases that have the greatest influence on tailwater algal communities include (1) daily and seasonal constancy of water temperatures, (2) modifications in nutrient regimes, (3) reduced sediment and increased water clarity, (4) formation of stable armored substrates, (5) fluctuations in water levels that produce daily drying and wetting cycles, and (6) reductions in seasonal flow variability and alterations in the timing or occurrence of extreme flows (Blinn et al. 1998). These conditions allowed ubiquitous *Cladophora glomerata* (a filamentous green algae) to become the dominant algal species below Glen Canyon Dam within 6 years of dam closure in 1963 (Czarnecki et al. 1976; Carothers and Minckley 1981; Blinn et al. 1989, 1998; Stanford and Ward 1991). This species remained dominant until 1995 (Blinn and Cole 1991; Blinn et al. 1995; Benenati et al. 1998). Changes in flow regimes (e.g., repeated episodes of exposure and desiccation of the varial zone) and diluted nutrient concentrations associated with higher reservoir volumes caused the decrease in dominance of *Cladophora* (Benenati et al. 1998, 2000, 2002). Prior to June 1995, *Cladophora* comprised 92% of the phytobenthic community, but it decreased to <50% after that time (Benenati et al. 2000). The aquatic flora is now dominated by miscellaneous algae, macrophytes, and bryophytes (MAMB) including filamentous green algae (mainly *Ulothrix zonata* and *Spirogyra* spp.), the stonewort *Chara contraria*, the aquatic moss *Fontinalis* spp., and the macrophyte *Potamogeton pectinatus*. *Cladophora* is still present, but in much reduced levels, probably due to changes in reservoir and river chemistry and discharge regimes (Benenati et al. 2000; NPS 2005a; Yard and Blinn 2001).

Cladophora occurs along the entire course of the river; however, its abundance decreases downstream (Blinn and Cole 1991; Shannon et al. 1994; Shaver et al. 1997; Stevens, Shannon et al. 1997). This decrease results from high suspended sediment loads contributed from the major perennial tributaries, particularly the Paria River and Little Colorado River (Blinn et al. 1995). Suspended sediments reduce photosynthetic efficiency and scours *Cladophora* from substrates (Blinn et al. 1995; Hall et al. 2015).

Cladophora is colonized by a wide variety of diatoms (a group of unicellular or colonial algae) and macroinvertebrates because it can offer protection from predators, food, or a substrate that is anchored against flow disturbance (Dodds and Gudder 1992). Diatoms are the dominant food in the tailwaters of Glen Canyon Dam, but become less important downstream, where bacteria play a more important role in the food web (Blinn et al. 1992). *Cladophora* that becomes detached from the substrate in Glen Canyon is exported downstream where it enters the detrital pathways (Angradi and Kubly 1993, 1994).

The cyanobacteria *Oscillatoria* is co-dominant with *Cladophora* in Marble Canyon and dominates farther downstream in the Grand Canyon due to its tolerance of exposure to air and lower light levels compared to *Cladophora* (Blinn et al. 1992; Stevens, Shannon et al. 1997). Fewer diatoms occur on *Oscillatoria* compared to *Cladophora* (Shannon et al. 1994). Closely attached (adnate) diatoms dominate those that do occur on *Oscillatoria*, while upright or stalked diatoms dominate those that occur on *Cladophora*. Macroinvertebrates and fishes more easily consume the upright diatoms. While *Oscillatoria* provides cover for burrowing midges and aquatic worms, it has little food value for macroinvertebrates (Blinn et al. 1992). Energy from macroinvertebrate biomass associated with tufts of *Cladophora* is 10 times higher than for *Oscillatoria*. Therefore, replacement of *Cladophora* by *Oscillatoria* indirectly reduces potential energy flow in the Colorado River food web (Shaver et al. 1997).

Submerged macrophytes collected in the mainstem included horned pondweed (*Zannichellia palustris*), Canadian waterweed (*Elodea canadensis*), Brazilian elodea (*Egeria densa*), pondweed (*Potamogeton* spp.), aquatic moss (*Fontinalis* spp.), and muskgrass (*Chara* spp. [green alga]) (Carothers and Minckley 1981; Valdez and Speas 2007).

The distribution, ecological importance, and favorable temperature range for select primary producer taxa that occur downstream of Glen Canyon Dam are summarized in Table F-5 (Appendix F).

3.5.1.2 Plankton

Plankton occurring in the Colorado River downstream from Glen Canyon Dam includes both phytoplankton and zooplankton. The phytoplankton population in the Colorado River downstream of the dam is diverse, but sparse (numbers never exceeded 3 million organisms/m^3 [3,000 organisms/L]), and decreased with distance downstream of Lees Ferry. A total of 122 species were identified, with diatoms being dominant. In general, the phytoplankton of the Colorado River is considered relatively unproductive due to a combination of high flow rates, low temperatures, elevated turbidity (with increasing distance from the dam), and scouring action by rapids and suspended solids, which limit reproduction and survival (Sommerfeld et al. 1976).

The factors that regulate zooplankton in the Colorado River below Glen Canyon Dam are the distribution and abundance of zooplankton in Lake Powell and operations of the dam (AZGFD 1996; Speas 2000). Low levels of Lake Powell may result in increases in the composition and density of zooplankton downstream as waters are withdrawn from layers closer to the surface (Reclamation 1995). Cole and Kubly (1976) concluded that most zooplankton in the Colorado River originated from Lake Powell or tributaries (primarily Elves Chasm and Tapeats and Diamond Creeks). Mean zooplankton density in the 352 km of the Colorado River downstream of Glen Canyon Dam was 614 organisms/m^3 (0.614 organisms/L) (Benenati et al. 2001).

It has been reported that backwater areas are localities where zooplankton populations can persist (Haury 1986), and that zooplankton densities in backwaters are significantly higher than those from the main channel (AZGFD 1996). Backwaters were thought to support more zooplankton because they are more stable habitats and may retain nutrients that benefit both phytoplankton and zooplankton (AZGFD 1996). Some production of zooplankton occurs in eddies, backwaters, and other low-velocity areas (AZGFD 1996; Stanford and Ward 1986; Blinn and Cole 1991). However, given that even under stable flows waters in backwaters are recycled 1.5 to 3.4 times per day, it seems unlikely that water-column resources such as zooplankton could ever become substantially higher in backwaters than in the mainstem river (Behn et al. 2010).

The temperature requirements for select zooplankton taxa are summarized in Table F-6 (Appendix F).

3.5.1.3 Macroinvertebrates

Temperature and suspended sediment alterations associated with Glen Canyon Dam, and operations of Glen Canyon Dam itself, resulted in a food base with low species diversity. Although productivity of the food base is high in the Glen Canyon reach, food base production in the Grand Canyon is extremely low, falling in the bottom 10% of production values for streams and rivers throughout the world (Cross et al. 2013). Owing to these changes in the physical template of the river, coupled with intentional and accidental introductions of nonnative invertebrates, the food base consists of both native and nonnative species. The abundant aquatic macroinvertebrates within Lees Ferry include *Gammarus lacustris* (an introduced nonnative amphipod), midges (order Diptera, family Chironomidae), snails (*Physella* sp. and *Fossaria obrussa*), and segmented worms (especially Lumbricidae and Lumbriculidae), which are associated with *Cladophora* beds, as well as ooze- and gravel-dwelling worms (Naididae and Tubificidae), fingernail clams in the family Sphaeriidae (*Pisidium variable* and *P. walkeri*), and the planarian *Dugesia* spp. (Blinn et al. 1992; Stevens, Shannon et al. 1997). Prior to 1995, gastropods (snails) were infrequent but have since increased in abundance due to invasion by the nonnative New Zealand mudsnail (*Potamopyrgus antipodarum*) (Valdez and Speas 2007; Cross et al. 2010). This species is discussed later in this section.

Glen Canyon Dam limits the downstream transport of terrestrial materials such as insects, leaf litter, and woody debris. This reduction of organic input, coupled with low temperature variability and highly variable discharges, can contribute to decreased biodiversity and density of macroinvertebrates (Kennedy et al. 2016), particularly within the Glen Canyon reach. Seasonal turbidity increases, particularly from the confluence of the Paria River to Lake Mead, and reduces overall invertebrate biomass. The decrease in light penetration lowers primary production and favors the growth of the less nutritious cyanobacteria *Oscillatoria* in the lower reaches of the Colorado River (Blinn et al. 1999; Hall et al. 2012).). Macroinvertebrates are not generally associated with *Oscillatoria* because it is very compact, has little surface area for colonization, and largely lacks epiphytic diatoms (Blinn et al. 1995).

In contrast to insects, *Gammarus* and other non-insect aquatic macroinvertebrates can complete their development over a relatively wide temperature range (Vinson 2001), and non-insect aquatic macroinvertebrates lack a terrestrial life stage so their entire life cycle occurs in the river. *Gammarus* is largely replaced by midges and blackflies below the Paria River (Blinn et al. 1992; Seegert 2010; Donner 2011). The decrease in standing stock of *Gammarus* with distance from Glen Canyon Dam (Blinn and Cole 1991; Blinn et al. 1992) corresponds to a decrease in *Cladophora* biomass and associated epiphytic diatoms downriver (Hardwick et al. 1992). Although blackflies and midges are relatively less prevalent in Glen Canyon, they support more than half of the rainbow trout (*Oncorhynchus mykiss*) production in that reach (Cross et al. 2011). The 2008 HFE caused a 60% decline in overall invertebrate production that was driven by a large reduction in the production of nonnative New Zealand mudsnails (Cross et al. 2011). However, the production of midges and blackflies increased by 30 and 200%, respectively, in the year following the HFE, and these insects supported a 200% increase in rainbow trout production (Cross et al. 2011).

The relatively high densities of blackfly larvae in the downstream reaches of the Colorado River suggest the presence of smaller food particles (e.g., bacteria) in these reaches (Blinn et al. 1992; Wellard Kelly et al. 2013). Being filter feeders, blackflies are more common in high-velocity areas with little algal cover, including hard, smooth substrates and driftwood lodged among rocks. Limited data suggest that the blackfly assemblage in the river has changed from at least a five-species assemblage to a near monoculture of *Simulium arcticum* (Blinn et al. 1992).

The Colorado River in Glen and Grand Canyons supports very few mayflies, stoneflies, or caddisflies because of a combination of stressors, including altered temperature regimes and a large varial zone (Stevens, Shannon, et al. 1997; Kennedy et al. 2016). Cold water released from

Glen Canyon Dam can prevent aquatic insect eggs from hatching and may limit successful recruitment of these orders from warmer tributaries (Oberlin et al. 1999), while a large varial zone associated with hydropower production leads to desiccation-induced mortality of insect eggs laid along river edge habitats (Kennedy et al. 2016). The caddisfly *Ceratopsyche oslari* occurs throughout the Colorado River but at a low abundance (Blinn and Ruiter 2009). Haden et al. (1999) believe that interspecific interactions between *Gammarus* and the net-building *C. oslari* may contribute to the caddisfly's limited occurrence in the Colorado River below Glen Canyon Dam. Since 1994, recent colonizers (possibly as a result of reduced discharge variability from Glen Canyon Dam) throughout the river include caddisflies (*Hydroptila arctica*, *Rhyacophila* spp., *C. oslari*, and others), true flies (*Bibiocephala grandis* and *Wiedemannia* spp.), mayflies (*Baetis* spp.), beetles (*Microcylloepus* spp.), planarians, and water mites (Shannon et al. 2001). However, caddisflies and mayflies remain relatively sparse in the Colorado River, especially upstream of the Paria River. Tables F-2 through F-4 (Appendix F) present the biomass, production, and abundance of invertebrates, respectively, over the course of 3 years at various locations in the Colorado River.

Flow fluctuations and repeated inundation and exposure can have a significant impact on food base organisms in the varial zone. Warm air temperatures in summer or subfreezing air temperatures in winter can cause mortality of macroinvertebrates stranded in the varial zone (Gislason 1985). The varial zone probably provides poor habitat for species with multiple life history stages (Jones 2013b). Dewatering within the varial zone may adversely impact areas where adult aquatic insects either emerge or deposit eggs (Vinson 2001; Kennedy et al. 2016).

Drifting macroinvertebrates, particularly blackflies and midges, are an important food resource for rainbow trout (McKinney and Persons 1999) and other fishes. Flow regime, discharge, and distance from the dam influence drift of macroinvertebrates in the Colorado River (Shannon et al. 1996; Stevens et al. 1998; Sublette et al. 1998; Kennedy et al. 2014). In general, a positive correlation exists between invertebrate drift concentrations and flow magnitude; however, reduced flow can increase stream drift through behavioral factors such as crowding and avoidance of desiccation (Blinn et al. 1995; Kennedy et al. 2014). The density of invertebrates on the river bottom is also an important control of invertebrate drift concentrations (Kennedy et al. 2014). Tributary and terrestrial insects compose a small portion of the stream drift in the Colorado River corridor (Shannon et al. 1996). It is possible that terrestrial invertebrate drift is high during and immediately after rainstorms and is therefore a rare but locally important resource for mainstem Colorado River fishes (Shannon et al. 1996).

Table F-7 (Appendix F) summarizes information on the distribution, importance to higher trophic levels, and temperature range for common macroinvertebrates that occur downstream of Glen Canyon Dam.

Tribal Perspectives on Aquatic Food Base

The Zuni believe that macroinvertebrates are underwater species that are not yet ready for this world, and any disturbance to them could have negative consequences. The river's life begins at the headwaters. The river is the umbilical cord to the earth, and through the Zuni religion, prayers, and songs there is also an invisible cord to the Zuni. This statement about underwater species relates to the Zuni history, as Zunis believe that their most ancient ancestors emerged onto this world only when they were ready for emergence. To force an aquatic species to change is to impede the species' natural development and future progress, a violation of Zuni beliefs about the world's natural order.

3.5.1.4 Nonnative Invasive Species

Some nonnative species have been introduced to supplement the aquatic food base. Because of the low benthic food base noted in the late 1960s, Arizona Game and Fish Department (AZGFD) biologists introduced macroinvertebrates into the Glen Canyon reach, including crayfish, snails, damselflies, caddisflies, crane flies, midges, true bugs, beetles, and leeches (McKinney and Persons 1999). These introductions were not monitored for a sufficient length of time to determine their success; however, most of these taxa did not persist in the river (Carothers and Minckley 1981; Blinn et al. 1992). *Gammarus lacustris* was also introduced into the Glen Canyon reach in 1968 to provide food for native and nonnative fishes (Ayers et al. 1998). *Gammarus* and midges have become important components of the aquatic food base.

Other nonnative invasive species that have potentially detrimental effects on both the food base and fish communities have become established in the Colorado River below Glen Canyon Dam. New Zealand mudsnail was first detected in Glen Canyon in 1995. By 1997, densities on cobble/gravel substrates reached about 3,390/ft^2. Densities averaged 5,567/ft^2 between 1997 and 2006, except for 2000, when densities averaged 20,540/ft^2. High densities that year coincided with experimental steady flows. Although the New Zealand mudsnail can withstand short periods of desiccation, its density is generally higher in systems with constant flows (see Section F.2.1.3 of Appendix F). The New Zealand mudsnail has dispersed downstream through Grand Canyon and was documented in Lake Mead in 2009 (Sorensen 2010). The mudsnail accounted for 20 to 100% of the macroinvertebrate biomass at six cobble bars studied in the Colorado River. The snails probably consume the majority of the available epiphytic diatom assemblage. The New Zealand mudsnail is a trophic dead-end and may adversely affect the food base in the Colorado River (Shannon, Benenati, et al. 2003). Epiphytic diatom biomass estimates at Lees Ferry were an order of magnitude lower in 2002 compared to 1992 (before New Zealand mudsnails were present) (Benenati et al. 1998; Shannon, Benenati et al. 2003). However, the biomass of other dominant aquatic food base taxa has been variable and not apparently influenced by the presence of the snails (Cross et al. 2010). However, at high population levels (e.g., ≥9,300 individuals/ft^2), New Zealand mudsnails can substantially modify lower trophic levels (Hall et al. 2006).

The New Zealand mudsnail can directly affect native species by consuming a large proportion of the primary production (especially periphyton), competing with native snails and other grazing invertebrates, and negatively impacting both invertebrates and vertebrates at higher trophic levels in aquatic food webs that depend on the aquatic invertebrate food base (Riley et al. 2008; Hall et al. 2003, 2006; Vinson and Baker 2008). At high densities, the New Zealand mudsnail may compete with other macroinvertebrates for food (e.g., diatoms) or space (Kerans et al. 2005). Hall et al. (2006) suggest that the New Zealand mudsnail is sequestering a large fraction of the carbon available for invertebrate production and altering food web function.

The New Zealand mudsnail has a good chance of being transported by either biological or physical vectors because of its small size and locally high population density (Haynes and Taylor 1984). Recreational fishing and fish stocking have been implicated in the spread and introduction of the New Zealand mudsnail (Moffitt and James 2012). The New Zealand mudsnail can also be carried by waterfowl from one system to another and by fish within a system (Haynes et al. 1985).

Vinson and Baker (2008) evaluated the ability of rainbow trout to assimilate New Zealand mudsnails. They found that juvenile rainbow trout will readily ingest the snails but receive little nutritional value because the snails have an operculum that protects them from digestive agents. Also, trout lack pharyngeal teeth that would assist in grinding snail shells. Trout-fed mudsnails lost 0.14 to 0.48%/d of their initial body weight, while those fed amphipods gained 0.64 to 1.34%/d of their initial body weight. Only 15% of New Zealand mudsnails were assumed to have been digested, 32% were dead but present in their shells and assumed to be undigested, and 53% were alive. The results confirm that North American trout fisheries face potential negative impacts from the New Zealand mudsnail invasion (Vinson and Baker 2008). Although the New Zealand mudsnail occurs throughout the river from the Glen Canyon Dam to Lake Mead, its densities tend to be much higher in the upper reaches of the river (Cross et al. 2013). For example, in the Glen Canyon reach, densities of mudsnails were an order of magnitude higher than downstream in Grand Canyon (Cross et al. 2013).

A few nonnative invasive invertebrates are fish parasites that use food base organisms as an intermediate host. For example, the internal parasite *Myxobolus cerebralis*, which causes whirling disease in salmonids, uses the oligochaete worm *Tubifex tubifex* as an intermediate host (see Section 3.5.3.1 for additional information on whirling disease). The parasitic trout nematode (*Truttaedacnitis truttae*) is present in rainbow trout in the Glen Canyon reach. The ecological impact of the infestation is poorly known, but may influence food consumption, impair growth, and reduce reproductive potential and survival of rainbow trout. The nematode may require an intermediate host such as a copepod or other zooplankton taxa (McKinney, Robinson, et al. 2001).

The Asian tapeworm (*Bothriocephalus acheilognathi*) was first introduced into the United States with imported grass carp (*Ctenopharyngodon idella*) and was discovered in the Little Colorado River by 1990. It now parasitizes the humpback chub population from the Colorado and Little Colorado Rivers. The tapeworm could infect all species of native and nonnative fish species in the Little Colorado River (USGS 2004). Cyclopoid copepods are intermediate hosts for the tapeworm; however, fish that prey upon small infected fish can acquire tapeworm infections as well. Thus, large humpback chub that normally consume little zooplankton can become infected by preying upon smaller infected fish (USGS 2004).

Asian tapeworms were recovered in all fish species sampled from the Little Colorado River but were rare in suckers, rainbow trout, and catfish (mean ≤0.08/fish). Their highest abundance and prevalence were in humpback chub (mean 18.36/fish with 84% of fish infected). The abundance and prevalence of the tapeworm in nonnative cyprinids, such as the fathead minnow (*Pimephales promelas*—mean 0.84/fish, with 23% of fish infected), red shiner (*Notropis lutrensis*—mean 1.2/fish, with 63% of fish infected), and common carp (*Cyprinus carpio*—mean 3.5/fish, with 52% of fish infected), as well as the plains killifish (*Fundulus zebrinus*—mean 1.26/fish, with 15% of fish infected), implicates any of these species as being potential hosts that introduced the tapeworm into the Little Colorado River. It is also possible that bait bucket transfers into the upper reaches of the Little Colorado River or into the Colorado River may have been responsible for the introductions (Choudhury et al. 2004).

Increased body loads of the parasitic copepod known as anchor worm (*Lernaea cyprinacea*) and the Asian tapeworm cause poorer body condition in humpback chub from the Little Colorado River. For fishes collected from 1996 to 1999, prevalence of the anchor worm was found to be 23.9%, and the mean intensity was 1.73/fish in the Little Colorado River compared to 3.2% and 1.0/fish in the Colorado River. The prevalence of Asian tapeworm was 51.0% and 252/fish in the Little Colorado River, but only 15.8% and 12/fish in the Colorado River. Differences in parasite density and abundance between the Little Colorado River and Colorado River are caused by temperature differences. Temperatures in the Colorado River near the Little Colorado River do not reach those necessary for either parasite to complete its life cycle; thus, these parasites were probably contracted while the humpback chub was in the Little Colorado River (Hoffnagle et al. 2006). Table F-8 (Appendix F) presents the temperature requirements for the Asian tapeworm, anchor worm, and the trout nematode.

Table F-8 (Appendix F) summarizes information on the temperature requirements for the Asian tapeworm, anchor worm, and trout nematode. While not included in the table, whirling disease infection prevalence and severity in salmonids is greatest at 10 to 15°C (Steinbach Elwell et al. 2009).

There are concerns about the potential for other nonnative invasive species to become established in the future and further impact the condition of the aquatic food base. The quagga mussel (*Dreissena bugensis*) is one species of particular concern. It can alter food webs by filtering phytoplankton and suspended particulates (Benson et al. 2013). Although there was conflicting information as to the presence of quagga mussels in Lake Powell for a few years prior to 2012, a noticeable population had not yet developed in that year (NPS 2012c). However, as of 2014, thousands of adult quagga mussels have been observed within the reservoir on canyon walls, the Glen Canyon Dam, boats, and other underwater structures (Repanshek 2014). Quagga mussels established in Lake Powell may cause changes in dissolved nutrients, phytoplankton, and zooplankton within the reservoir, which would likely impact food web structure or trophic linkages below Glen Canyon Dam (Nalepa 2010). The quagga mussel was first detected in the Colorado River below Glen Canyon Dam in 2014 after it began to establish in Lake Powell.

As the population of quagga mussels develops in Lake Powell, the potential for mussel larvae to travel though Glen Canyon Dam increases. Those that survive could attach in low flow areas of the Colorado River, but it is not known if they could reach high numbers (NPS 2012c). The risk of the quagga becoming established within the Colorado River Ecosystem is low, except in the Glen Canyon reach, where lower suspended sediment and higher nutrient levels (compared to downstream reaches) favor its establishment (Kennedy 2007). It is unlikely to establish at high densities within the river or its tributaries because of high suspended sediment, high ratios of suspended inorganic/organic material, and high water velocities, all of which interfere with the ability of the quagga mussel to effectively filter food. High concentrations of sand may cause abrasion and physically damage its feeding structures (Kennedy 2007). In addition, it only takes 5 days for water to travel from Glen Canyon Dam to Diamond Creek (Kennedy 2007), so few quagga mussel larvae exported from Lake Powell will be large enough (i.e., >0.2 mm) to colonize the mainstem before they reach Lake Mead, where there is already an established quagga population. Larval mortality in the rapids of Grand Canyon also is likely to be high (Kennedy 2007). Quagga mussels are being found in the river below the dam in relatively low numbers; one mussel has been reported from as far downstream as River Mile 209.

If the quagga mussel obtained moderate densities in Lees Ferry, estimates of filtration capacity indicate they are unlikely to substantially alter the quality (e.g., nutrient concentrations, suspended organic matter concentrations) of water within or exported from Lees Ferry (Kennedy 2007).

3.5.1.5 Food Web Dynamics

Primary production, specifically diatoms, forms the base of the aquatic food web in Glen Canyon. In contrast, a combination of primary production and terrestrial and tributary inputs of organic matter is the basis of the aquatic food web in Marble and Grand Canyons, but high-quality algal matter supports the food web to an extent that is disproportionate to its availability. Midges and blackflies principally fuel the production of native and nonnative fishes, and fish production throughout the river appears to be limited by the availability of high-quality prey, particularly midges and blackflies, and fish may exert top-down control on their prey (Carlisle et al. 2012).

The food web within Glen Canyon is rather simple. Complexity increases with distance from the dam (Figures G-2 and G-3 in Appendix G) (Cross et al. 2013). The New Zealand mudsnail and nonnative rainbow trout dominate the food web in the Glen Canyon reach of the Colorado River. The simple structure of this food web has a few dominant energy pathways (diatoms to a few invertebrate taxa to rainbow trout) and large energy inefficiencies (i.e., <20% of invertebrate production consumed by fishes). Epiphytic diatoms, *Gammarus*, midges, and blackflies provide the primary food base for rainbow trout (Cross et al. 2013).

Below large tributaries, invertebrate production declines about 18 fold, while fish production remains similar to upstream sites. However, sites below large tributaries have increasingly diverse and detritus-based food webs. Midges and blackflies are the dominant invertebrates consumed in downstream reaches (Cross et al. 2013). Fish populations are food-limited throughout most of the mainstem, and tend to consume all of the available invertebrate production in downstream reaches (Cross et al. 2013).

3.5.2 Native Fish

Human activities have greatly affected the fish fauna of the Colorado River between Glen Canyon Dam and Lake Mead. Warmwater nonnative fish were introduced as early as the late 1880s (Carothers and Brown 1991). Overall, the Colorado River Basin once contained a unique assemblage of 35 native fish species, 74% of which were endemic (Minckley 1991). Relatively little information is available regarding the fish community prior to the construction of Glen Canyon Dam. Limited sampling in Glen Canyon before dam construction (conducted from 1957 to 1959) reported only two species from the mainstem proper: the nonnative channel catfish (*Ictalurus punctatus*; about 90% of the captures) and the native flannelmouth sucker (*Catostomus latipinnis*; about 10% of the catch) (Woodbury et al. 1959; McDonald and Dotson 1960). In contrast, mainstem backwaters and tributaries of the Colorado River within the Glen Canyon reach had a more diverse fish community, with 14 nonnative and 6 native species, dominated by the native flannelmouth sucker and speckled dace (*Rhinichthys osculus*).

Prior to Glen Canyon Dam closure in 1963, the river carried high sediment loads and, depending on season, flows and water temperatures varied widely (see Section 3.3.3). Construction and closure of Glen Canyon Dam permanently altered the river downstream, creating a relatively clear river with nearly constant year-round cold temperatures (<12°C [54°F]) and daily fluctuating but seasonally modulated flows based on tributary inflows and water storage and electrical generation needs (Reclamation 1995; NPS 2013e). As a consequence, the cold water temperatures in many miles of the main channel are below those needed for spawning, egg incubation, and growth of most native fish (Figure 3.5-1), and successful reproduction has been largely supported in tributaries (Reclamation 1995). In recent years, however, there has been some newly documented reproduction of native fish in portions of the lower Grand Canyon; adult and larval razorback suckers have been captured there (Bunch, Makinster, et al. 2012; Bunch, Osterhoudt et al. 2012; Albrecht et al. 2014; Rogowski and Wolters 2014; Rogowski, Wolters, et al. 2015). Razorback suckers have also been recently observed in the San Juan River arm of Lake Powell (Francis et al. 2015). Colorado River tributaries continue to exhibit natural flow and temperature regimes conducive to native fish spawning and rearing. Most native fish in the mainstem from the dam to the Little Colorado River are large juveniles and adults, while earlier life stages rely extensively on more protected and warmer near-shore habitats, primarily backwaters (Johnstone and Lauretta 2007; Ackerman 2008). The habitats and reproduction of native species in the system are discussed in more detail in later sections.

In addition to the effects of the altered mainstem physical environment on the reproduction, growth, survival, and distribution of native fishes in the Colorado River below Glen Canyon Dam, past introductions of nonnative fish species, both intentional and accidental, have affected native fish in the Colorado River and its tributaries downstream of Glen Canyon Dam. Coldwater and/or warmwater nonnative fish exist in all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam (see Section 3.4.4). These species can dominate the fish community in some areas and may threaten native species survival. Nevertheless, habitats in the Colorado River and its tributaries in GCNP support the largest remaining endangered humpback chub population, and this population has been growing since the late 1990s (Coggins and Walters 2009) and is now estimated at approximately 11,000 adults (Yackulic et al. 2014). Over

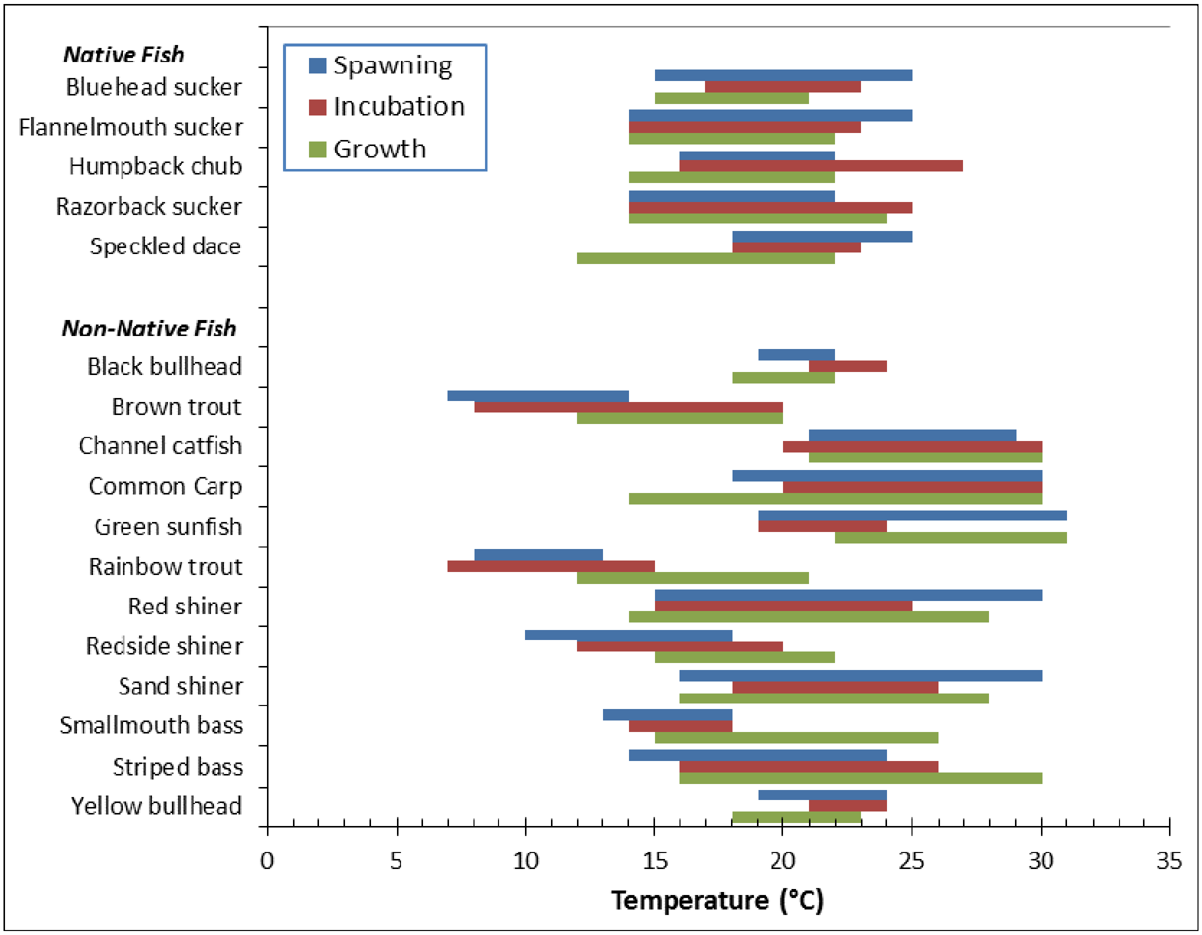

FIGURE 3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and Nonnative Fishes of the Colorado River System below Glen Canyon Dam (Source: Valdez and Speas 2007)

this same time period, the Grand Canyon fish community has also shifted toward a more dominant native species component (Lauretta and Serrato 2006; Johnstone and Lauretta 2007; Ackerman 2008; Makinster et al. 2010). It is hypothesized that the recent shift from nonnative to native fish is due in part to warmer than average water temperatures and the decline of coldwater salmonids (Ackerman 2008; Andersen 2009; Reclamation 2011c; Yackulic et al. 2014).

There are 11 species of native fishes that occur, may occur, or historically have occurred within the study area (Table 3.5-1). Among these native species, five species—the humpback chub, razorback sucker (*Xyrauchen texanus*), bluehead sucker (*Catostomus discobolus*), flannelmouth sucker, and speckled dace—occur within the mainstem and its tributaries. Three other species—the Zuni bluehead sucker (*Catostomus discobolus yarrowi*), Little Colorado sucker (*Catostomus latipinnis* sp. 3), and Little Colorado spinedace (*Lepidomeda vittata*)—are endemic to the upper reaches of the Little Colorado River. The remaining three species—the bonytail chub (*G. elegans*), roundtail chub (*G. robusta*), and Colorado pikeminnow (*Ptychocheilus lucius*)—have been extirpated from the mainstem between Glen Canyon Dam

TABLE 3.5-1 Native Fish of the Colorado River through Glen and Grand Canyons

Species	Listing Status[a]	Presence in Project Area[b]
Humpback chub (*Gila cypha*)	ESA-E, CH; AZ-SGCN	Lake Powell, Paria River confluence to Separation Canyon, Little Colorado River, Havasu Creek
Bonytail chub (*Gila elegans*)	ESA-E, CH; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon
Razorback sucker (*Xyrauchen texanus*)	ESA-E, CH; AZ-SGCN	Lake Powell; Lake Mead upstream to Lava Falls
Colorado pikeminnow (*Ptychocheilus lucius)*	ESA-E; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon.
Bluehead sucker (*Catostomus discobolus*)	AZ-SGCN	Paria River to Lake Mead, including tributaries
Flannelmouth sucker (*Catostomus latipinnis*)	NL	Lake Powell to Lake Mead
Speckled dace (*Rhinichthys osculus*)	NL	Glen Canyon Dam to Lake Mead, including tributaries

[a] ESA = Endangered Species Act; E = listed as endangered; CH = federally designated critical habitat in project area; AZ-SGCN = Arizona Species of Greatest Conservation Need; NL = not listed.

[b] Habitat and life history information is presented in species-specific discussions in this section.

Sources: 56 FR 54957; AZGFD (2001a,b; 2002a,b; 2003a); Andersen (2009); Bezzerides and Bestgen (2002); Coggins and Walters (2009); Francis et al. (2015); Makinster et al. (2010); Ptacek et al. (2005); Rees et al. (2005); Rinne and Magana (2002); FWS (2002a); Ward and Persons (2006); Woodbury et al. (1959); Gloss and Coggins (2005); GCMRC (2014); Albrecht et al. (2014).

and Hoover Dam. The extirpated species and those found only in the upper reaches of the Little Colorado River are considered outside the affected area considered in this EIS. Currently, five species of native fish are known to exist in the Colorado River between Glen Canyon Dam and Lake Mead; these are discussed in detail in the following sections.

3.5.2.1 Special Status Fish Species

Two species of native fish that are listed under the Endangered Species Act of 1973 (ESA) (16 USC 1531, as amended)—the humpback chub and the razorback sucker—occur in the potentially affected portions of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead. These two species are also designated as Arizona Species of Greatest Conservation Need (AZ-SGCN). In addition, two other native fish, the flannelmouth sucker and bluehead sucker, are included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a).

Humpback Chub

The humpback chub is a large, long-lived species endemic to the Colorado River system. This member of the minnow family may attain a length of 20 in., weigh 2 lb or more, and live as long as 40 years (Andersen 2009).

Distribution and Abundance. The humpback chub was federally listed as endangered in 1967. Historically, this species occurred throughout much of the Colorado River and its larger tributaries from below Hoover Dam upstream into Arizona, Utah, Colorado, and Wyoming (AZGFD 2001a). Currently, the humpback chub is restricted to six population centers, five in the upper Colorado River basin and one in the lower basin (FWS 2011a). The upper basin populations occur in (1) the Colorado River in Cataract Canyon, Utah; (2) the Colorado River in Black Rocks, Colorado; (3) the Colorado River in Westwater Canyon, Utah; (4) the Green River in Desolation and Gray Canyons, Utah; and (5) the Yampa River in Yampa Canyon, Colorado. The only population in the lower basin occurs in the Colorado River in Marble Canyon, the Grand Canyon, and Little Colorado River (FWS 2011a).

The Colorado River/Little Colorado River population is the largest of the six population centers of the humpback chub. Within the Grand Canyon, this species is most abundant in the vicinity of the confluence of the Colorado River and Little Colorado River (Paukert et al. 2006). In addition, eight other areas (aggregation areas) where humpback chub are, or have been, regularly collected have been identified; these aggregation areas are located at 30-Mile, Lava Chuar-Hance, Bright Angel Creek inflow, Shinumo Creek inflow, Stephen Aisle, Middle Granite Gorge, Havasu Creek inflow, and Pumpkin Spring (Figure 3.5-2; Valdez and Ryel 1995). In addition, since 2009, translocations of humpback chub have been made by the U.S. Fish and Wildlife Service (FWS) to introduce juvenile fish upstream of Chute Falls in the Little Colorado River, and by NPS to introduce juvenile fish into Shinumo and Havasu Creeks, with the goal of establishing additional spawning populations within the Grand Canyon (NPS 2012b, 2013g). Survey data collected in 2013, 2014, and 2015 suggest that translocated humpback chub have successfuly spawned in Havasu Creek (NPS 2013g). Sampling conducted between October 2013 and September 2014 in the western Grand Canyon between Lava Falls (RM 180) and Pearce Ferry (RM 280) collected 144 juvenile humpback chub during sampling of the small-bodied fish community, and 209 larval and juvenile humpback chub during sampling of the larval fish community (Albrecht et al. 2014). These results suggest that young humpback chub are using nursery and rearing habitats between RM 180 and RM 280 in the western Grand Canyon that are not clearly associated with any of the aggregation areas identified above.

Monitoring data show that from 1989 through 2001, there was a steady decline of adult humpback chub within the Little Colorado River aggregation in the Grand Canyon; estimated numbers declined from approximately 11,000 adults (age 4+) in 1989 to about 5,000 adults in 2001 (Coggins et al. 2006; Coggins and Walters 2009) (Figure 3.5-3). However, since about 2001, the downward population trend reversed, with the estimated number of adult fish

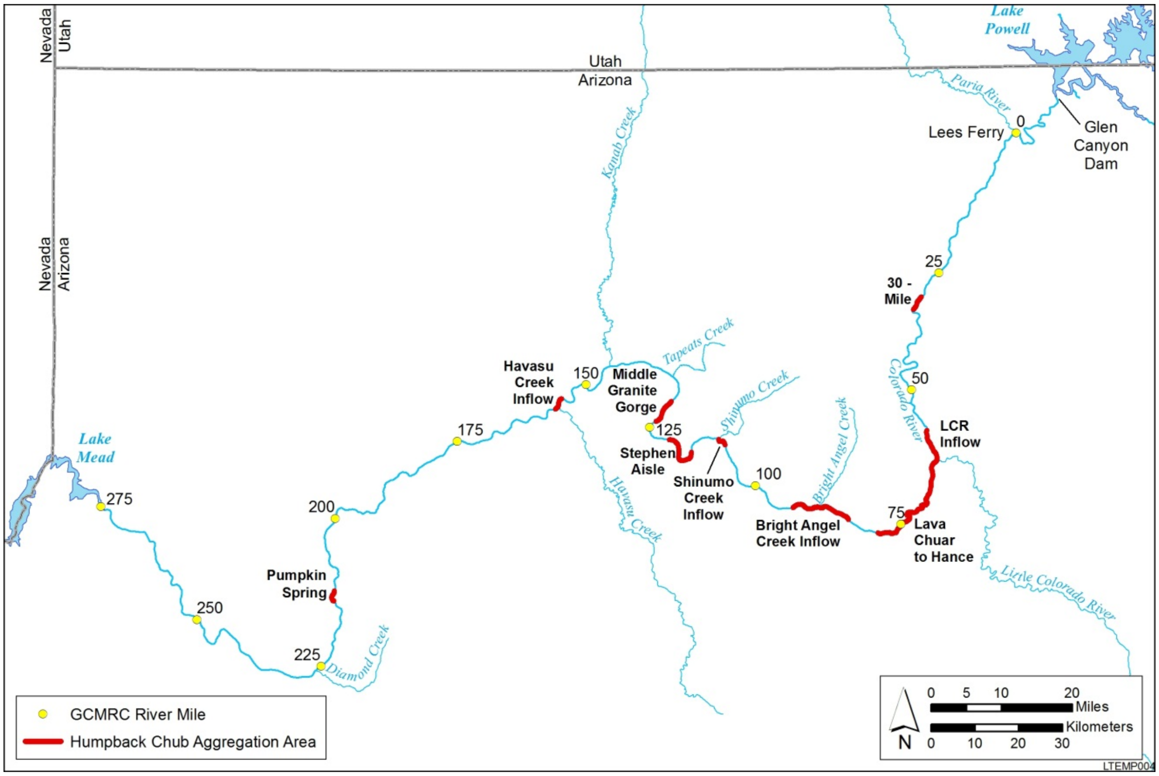

FIGURE 3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead (Sources: VanderKooi 2011; NPS 2013b)

increasing to approximately 8,000 fish by 2008 (Figure 3.5-3) (Coggins and Walters 2009). More recently, abundance estimates for 2009 to 2012 suggest the population has continued to increase to approximately 11,000 adults (Figure 3.5-4) (Yackulic et al. 2014). Factors suggested as being responsible for this estimated increase are discussed later in this section. In addition, recent preliminary population estimates for humpback chub aggregations suggest that humpback chub in several aggregations may have increased as a result of (1) translocations to Shinumo and Havasu Creeks; (2) good production in the Little Colorado River; (3) water temperatures that were about 1°C (1.8°F) warmer since the early 2000s (including significantly warmer than normal water temperatures in 2004, 2005, and 2011); and (4) declines in trout abundance at the Little Colorado River inflow due to implementation of trout control measures, a system-wide decline in trout abundance, or both (NPS 2013e; Yackulic et al. 2014).

Habitat. Throughout the humpback chub's current range, adults are found in turbulent, high-gradient canyon-bound reaches of large rivers (AZGFD 2001a) as well as in deep pools separated by turbulent rapids. Within the Grand Canyon, the humpback chub occurs primarily in the vicinity of the Little Colorado River (RM 30-110; Figure 3.5-2), with adults being associated with large eddy complexes. Converse et al. (1998) found that densities of subadult humpback chub in the mainstem Colorado River downstream of the Little Colorado River were greater along shoreline areas with vegetation, talus, and debris fans than in areas with bedrock, cobble,

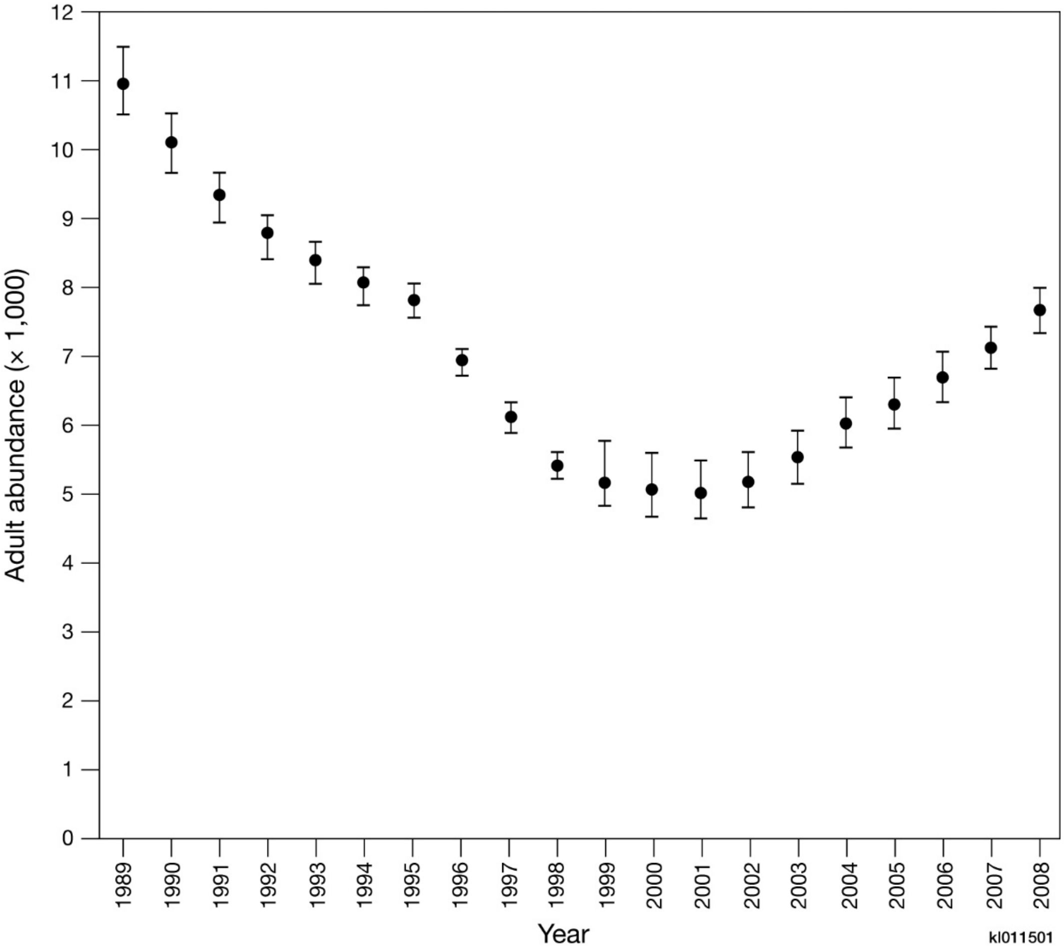

FIGURE 3.5-3 Estimated Adult Humpback Chub Abundance (Age 4+) from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age (Error bars represent minimum 95% confidence intervals and do not consider uncertainty in growth or mortality.) (Source: Coggins and Walters 2009)

and sand substrates. One recent mark-recapture study reported that approximately 87% of recaptured fish were collected in the same mainstem river reach or tributary where they were originally tagged, with 99% of all recaptures occurring in and around the Little Colorado River (Paukert et al. 2006). However, some of the marked fish were determined to have moved as much as 96 mi throughout the Grand Canyon. In the Little Colorado River, adults inhabit a variety of habitats, including pools and areas below travertine dams (AZGFD 2001a). More recently, a study conducted in 2010 examined the movement of 30 radio-tagged adult humpback chub in the Colorado River during 2 months of fluctuating flow followed by 2 months of steady flow (Gerig et al. 2014). The radio-tagged fish were found to use eddies extensively while avoiding runs. During both flow treatments, the tagged fish exhibited only small daily movements of about 33 ft/day, and no effect of flow was observed on either habitat selection or movement.

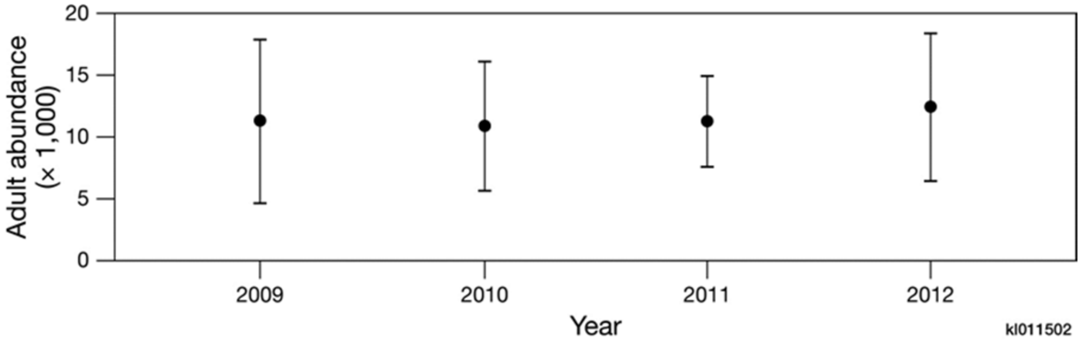

FIGURE 3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September, 2009 through 2012 (Error bars represent the 95% confidence intervals.) (Source: Yackulic et al. 2014)

The main spawning area for the humpback chub within the Grand Canyon is the Little Colorado River, which provides warm temperatures suitable for spawning and shallow low-velocity pools for larvae (Gorman 1994). Many of the larval fish remain in the Little Colorado River for one or more years, and growth rates and survival are relatively high compared to estimates for the colder waters of the mainstem Colorado River (Dzul et al. 2014). Spring abundance estimates for age-1 humpback chub within the Little Colorado River from 2009 to 2012 ranged from approximately 1,000 to more than 9,000 individuals (Dzul et al. 2014). Within the Little Colorado River, young humpback chub prefer shallow, low-velocity near-shore pools and backwaters; they move to deeper and faster areas with increasing size and age (AZGFD 2001a). In the mainstem of the Colorado River, young-of-the-year (YOY) fish may be found in backwater and other near-shore, slow-velocity areas that serve as nursery habitats (Valdez and Ryel 1995; Robinson et al. 1998; AZGFD 2001a; Stone and Gorman 2006). Juvenile humpback chub (<3 years old) have been collected in all types of near-shore habitats by the Humpback Chub Near-shore Ecology Study, with the highest numbers collected from talus slopes (Dodrill et al. 2015).

These near-shore habitats may be beneficial to the humpback chub (and other native fishes) as they provide shallow, productive, warm refugia for juvenile and adult fish (Reclamation 1995; Hoffnagle 1996). Temperature differences between main channel and near-shore habitats can be pronounced in backwaters and other low-velocity areas. The extent of warming is variable and depends on the timing of the daily minimum and maximum flows, the difference between air and water temperatures, and the topography and orientation of the backwater relative to solar insolation (Korman et al. 2006). For example, summertime water temperatures in backwaters have been reported to be as high as 25°C (77°F) while main channel temperatures are near 10°C (50°F) (Maddux et al. 1987). The amount of warming that occurs in backwaters is affected by daily fluctuations, which drain and fill backwater habitats with cold main channel waters (Valdez 1991; Angradi et al. 1992; AZGFD 1996; Behn et al. 2010). During the low steady summer flow experiment conducted in 2000, temperatures in one backwater were as much as 13°C (23°F) warmer than in the adjacent main channel during some portions of the day; temperature differences were much less at night (Vernieu and Anderson 2013). Backwater temperatures in summer have been reported to be as much as 2 to 4°C (3.6 to 7.2°F) warmer under steady flows than under fluctuating flows (Hoffnagle 1996; Trammell et al. 2002; Korman et al. 2006; Anderson and Wright 2007). In general, the levels of warming observed in nearshore areas and backwaters during the low summer steady flows in 2000 persisted only for short periods of time and were smaller than seasonal changes in water temperatures (Vernieu and Anderson 2013). Consequently, temperature effects on native fishes were probably small.

Although the use of thermal refugia such as backwaters has been documented in a variety of systems (e.g., Tyus and Haines 1991; Bodensteiner and Lewis 1992; Torgersen et al. 1999; Ebersole et al. 2001; Westhoff et al. 2014), the overall importance of backwater habitats in the Colorado River relative to humpback chub survival and recruitment is uncertain (Reclamation 2011c). While juvenile humpback chub have been reported to show positive selection for backwater habitats, the spatial extent of such habitats in the Colorado River is small compared to other nearshore habitats such as talus slopes (Dodrill et al. 2015). Dodrill et al. (2015) reported that the total abundance of juvenile humpback chub was much higher in talus than in backwater habitats, and that when relative densities were extrapolated using estimates of backwater prevalence after an HFE, the majority of juvenile humpback chub were still found outside of backwaters. This suggests that the role of HFEs in influencing native fish population trends in the Colorado River may be limited.

Life History. The humpback chub is primarily an insectivore, with larvae, juveniles, and adults all feeding on a variety of aquatic insect larvae and adults, including dipterans (primarily chironomids and simulids), Thysanoptera (thrips), Hymenoptera (ants, wasps, bees), and amphipods (such as *Gammarus lacustris*) (Kaeding and Zimmerman 1983; AZGFD 2001a; Cross et al. 2013). Feeding by all life stages may occur throughout the water column as well as at the water surface and on the river bottom.

The Grand Canyon humpback chub population reproduces primarily in the lower 8 mi of the Little Colorado River, although occasional spawning is suspected in other areas of the Colorado River as well (Valdez and Masslich 1999; Anderson et al. 2010; AZGFD 2001a). Adults move into the Little Colorado River from the Colorado River to spawn from March to May (Kaeding and Zimmerman 1983; Gorman and Stone 1999; FWS 2008). Relatively little spawning and juvenile rearing occur in the mainstem of the Colorado River, primarily because of the cold mainstem water temperatures (Andersen 2009). Mainstem spawning is suspected near 30-mile spring, or in other areas in the western Grand Canyon following the detection of larval humpback chub in recent years (Albrecht et al. 2014, Kegerries et al. 2015), although studies have not been completed to identify spawning areas or habitat in the Colorado River in the Grand Canyon. This species requires a minimum temperature of 16°C (61°F) to reproduce, but mainstem water temperatures typically have ranged from 7 to 12°C (45 to 54°F) because of water releases from Glen Canyon Dam (Andersen 2009). Drought-induced warming has resulted in mainstem water temperatures since 2003 consistently exceeding 12°C (54°F) in the summer and fall months. Although some increases in spawning may have played a role in the estimated increase in the humpback chub population in the system since that time, it is likely that the increased temperatures resulted in higher survival of juveniles in the mainstem (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014).

Following spawning, larvae have been reported to drift in the Little Colorado River from April through June, and many drift out into near-shore habitats of the Colorado River (FWS 2008). Robinson et al. (1998) estimated about 38,000 larval humpback chub drifted from the Little Colorado River into the mainstem in May and June 1993. Juveniles generally have lower monthly rates of movement than adults, with the exception of a high probability of juveniles being transported from the Little Colorado River to the Colorado River during high flows of the monsoon season, when numbers of juvenile humpback chub in the mainstem have been documented to increase by as much as 4,000 fish (Yackulic et al. 2014).

Although survival of larval and juvenile fish in the mainstem was once thought to be very rare because of seasonally constant, low water temperatures (Clarkson and Childs 2000), more recent information suggests that juveniles can successfully rear to adulthood in the Colorado River mainstem, at least under recent environmental conditions that include warmer water (Yackulic et al. 2014). Increasing water temperatures have been shown in the laboratory to increase hatching success, larval survival, larval and juvenile growth, and improve swimming ability and reduce predation vulnerability (Hamman 1982; Ward 2011; Ward and Morton-Starner 2015). Yackulic et al. (2014) postulated that, with warmer water, growth and survival of juveniles in the mainstem will be greater and result in increased mainstem recruitment, and thus contribute to the overall adult population. Increased water temperatures may also affect predation of YOY humpback chub by rainbow and brown trout (*Salmo trutta*) (Ward 2011; Ward and Morton-Starner 2015; Yard et al. 2011). Ward and Morton-Starner (2015) conducted laboratory studies that indicated predation success of rainbow trout on YOY humpback chub decreased from approximately 95 to 79% as water temperature increased from 10°C to 20°C (50°F to 68°F); predation success by brown trout was about 98% and did not change significantly over the same temperature range. Yard et al. (2011) examined the effects of temperature on trout piscivory in the Colorado River and reported no relationship between water temperature and the incidence of piscivory by rainbow trout, but a significant positive correlation was found between water temperature and the incidence of piscivory for the brown trout.

Factors Affecting Distribution and Abundance in the Grand Canyon. These factors include habitat alterations associated with dams and reservoirs and the introduction of nonnative fishes, which act as competitors and/or predators of the humpback chub (see Section 3.5.3.3) (AZGFD 2001a; Andersen 2009; Yard et al. 2011; Kennedy et al. 2013). The abundance and distribution of nonnative fishes are discussed in Section 3.5.3. In addition, the Colorado River now includes nonnative fish parasites, such as the Asian tapeworm and anchor worm, which may infect some humpback chub and affect survival (Clarkson et al. 1997; Andersen 2009). While coldwater releases from Glen Canyon Dam have limited reproduction and recruitment of humpback chub (and other native fishes) in the mainstem Colorado River, warmer water temperatures in the mainstem over the last decade have been sufficiently high to allow for modest growth, survival, and recruitment of humpback chub, contributing to the improving status of this species in the Grand Canyon (Reclamation 2011a; Yackulic et al. 2014).

Population estimates indicate that the number of adult humpback chub in the Grand Canyon increased from about 2001 to 2008 (Figures 3.5-3) and has been stable in recent years (Figure 3.5-4). A number of factors have been suggested as being responsible for the observed increases, including experimental water releases, trout removal, declines in trout abundance due to low DO levels during 2006, and drought-induced warming (Andersen 2009; Coggins and Walters 2009). Some experimental releases, such as the November HFE in 2004, may have adversely affected rainbow trout and improved humpback chub habitat along the main channel (Korman et al. 2010). However, the March 2008 HFE may have improved rainbow trout spawning habitat quality and age-0 survival rates (Korman et al. 2011) in the Glen Canyon reach. Following this, the abundance of rainbow trout (using catch-per-unit-effort as a surrogate for abundance) in this reach was reported to be about 300% larger in 2009 than in 2007 (about 3.9 fish per minute vs. 1.3 fish per minute, respectively) (Makinster et al. 2011), and a similar increase in rainbow trout abundance between 2007 and 2009 was observed at the Little Colorado River confluence (RM 56–69) (Kennedy and Ralston 2011). The effects of HFEs on trout abundance are discussed in more detail in Section 3.5.3.4.

Predation by rainbow and brown trout at the Little Colorado River confluence has been identified as an additional mortality source affecting humpback chub survival, reproduction, and recruitment (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2011). Predation by channel catfish and black bullhead (*Ictalurus melas*) are also thought to threaten humpback chub in the Grand Canyon, particularly if warmer water conditions occur (NPS 2013e). Because of their size, adult humpback chub are less likely to be preyed on by trout; however, emergent fry, YOY, and juvenile humpback chub are susceptible to predation in the mainstem Colorado River in the vicinity of the Little Colorado River (Yard et al. 2011).

Experimental removal of nonnative brown and rainbow trout was conducted in the Colorado River in the Grand Canyon between 2003 and 2006 (see Section 3.5.3.4). Twenty-three trips to remove trout from the vicinity of the confluence of the Little Colorado River (RM 56–RM 66) resulted in the removal of more than 23,000 nonnative fish (mostly rainbow trout). During this time, the rainbow trout population in the Colorado River in the vicinity of the Little Colorado River was decreased by more than 80% (Andersen 2009). Although the estimated humpback chub abundance increased during this time (Figure 3.5-3), the relationship between trout removal at the Little Colorado River, decreases in trout abundance, and increases in humpback chub abundance are not clear; trout abundance declined throughout the mainstem Colorado River downstream of Glen Canyon Dam during the same general time frame (Coggins et al. 2011). Increased numbers of humpback chub may also be attributable to a variety of other factors, including warmer water temperatures that occurred during this time, the HFE experimental flows, or a general decrease in rainbow trout abundance throughout the Grand Canyon ecosystem (Andersen 2009; Coggins et al. 2011; also see Section 3.5.3.4).

To aid in the mechanical trout removal effort, an experimental nonnative fish suppression flow regime from Glen Canyon Dam was implemented between January and March in 2003, 2004, and 2005 (Reclamation 2011c). These flows were intended to reduce rainbow trout abundance in the Glen Canyon reach by increasing mortality of incubating life stages. While the experimental flows were successful in reducing hatching and survival of young trout, density-dependent factors compensated with higher survival and growth of the remaining fish

(Korman et al. 2005), and thus the flows were not effective in limiting trout recruitment. However, those flows differ from the trout management flows being proposed under many alternatives in this EIS. See Section 3.5.3.4 for more detailed discussions on both the nonnative fish suppression flows and mechanical trout removal.

As previously discussed, the cold water temperatures in the main channel are below the temperature needed for spawning, egg incubation, and growth of the humpback chub (as well as for most native fish) (Figure 3.5-1). Survival of humpback chub young in the mainstem is thought to be low because of cold mainstem water temperatures (Clarkson and Childs 2000; Robinson and Childs 2001), which may limit hatching success, reduce larval survival and larval and juvenile growth (Coggins and Pine 2010), reduce swimming ability, and increase predation vulnerability (Ward and Bonar 2003; Ward 2011). Water temperatures in the mainstem Colorado River have generally been elevated over the last decade (Figure 3.5-5). These temperatures are not optimal for humpback chub spawning and growth. However, juveniles can now successfully rear to adulthood in the Colorado River mainstem, and mainstem recruitment is likely contributing to the overall adult population that now appears to be stable or increasing (Yackulic et al. 2014; Figure 3.5-4).

Water temperatures below Glen Canyon Dam began increasing in 2003 as a result of drought conditions that lowered the level of Lake Powell and resulted in the release of warmer water from the dam (Andersen 2009; Andersen et al. 2010); temperatures have remained elevated relative to operations during the 1980s and 1990s due to continued drought-induced lower Lake Powell reservoir levels and somewhat due to relatively high inflow in 2008, 2009, and 2011. In 2005, maximum mainstem water temperature exceeded 15°C (59°F) at Lees Ferry and approached 18°C (64°F) in the vicinity of the Little Colorado River (RM 61), the warmest temperature at those locations since the reservoir was filled in 1980 (Figure 3.5-5). Maximum water temperature in the mainstem at Lees Ferry reached about 14°C (57°F) in 2008 (USGS 2014b), similar to temperatures in 2003 when drought effects from low Lake Powell levels began to raise Glen Canyon Dam release temperatures. In 2011, maximum mainstem water temperatures at Lees Ferry and the Little Colorado River confluence (RM 61) reached about 15°C (59°F) and 16°C (61°F), respectively (Figure 3.5-5). This warmer water appears to have benefitted the humpback chub and other native fish, but they may also have benefitted nonnative warmwater species (e.g., channel catfish, striped bass) that are more abundant farther downstream in the Grand Canyon (Andersen 2009; Coggins and Walters 2009; Kennedy and Ralston 2011).

Tribal Perspectives on Humpback Chub. The Navajo people revere all creatures within the Grand Canyon and its tributaries as sacred and unique in maintaining the balance of the natural order and natural laws. But here it is important to note that the humpback chub is one of the utmost sacred beings that dwell within the Grand Canyon (more specifically the Little Colorado River). It is mentioned extensively within oral history when the Navajo Na adin Tahi of the waterway ceremony (voyager) took his journey through the canyon on a hallowed log with the turkey that ran alongside him. It is said that the voyager encountered many dangers and monsters that attempted to stop him in his journey. The humpback chub is a product of the one Teehooltsodii (Water Monster), as they are her children, and she negotiated with Haashch cheii

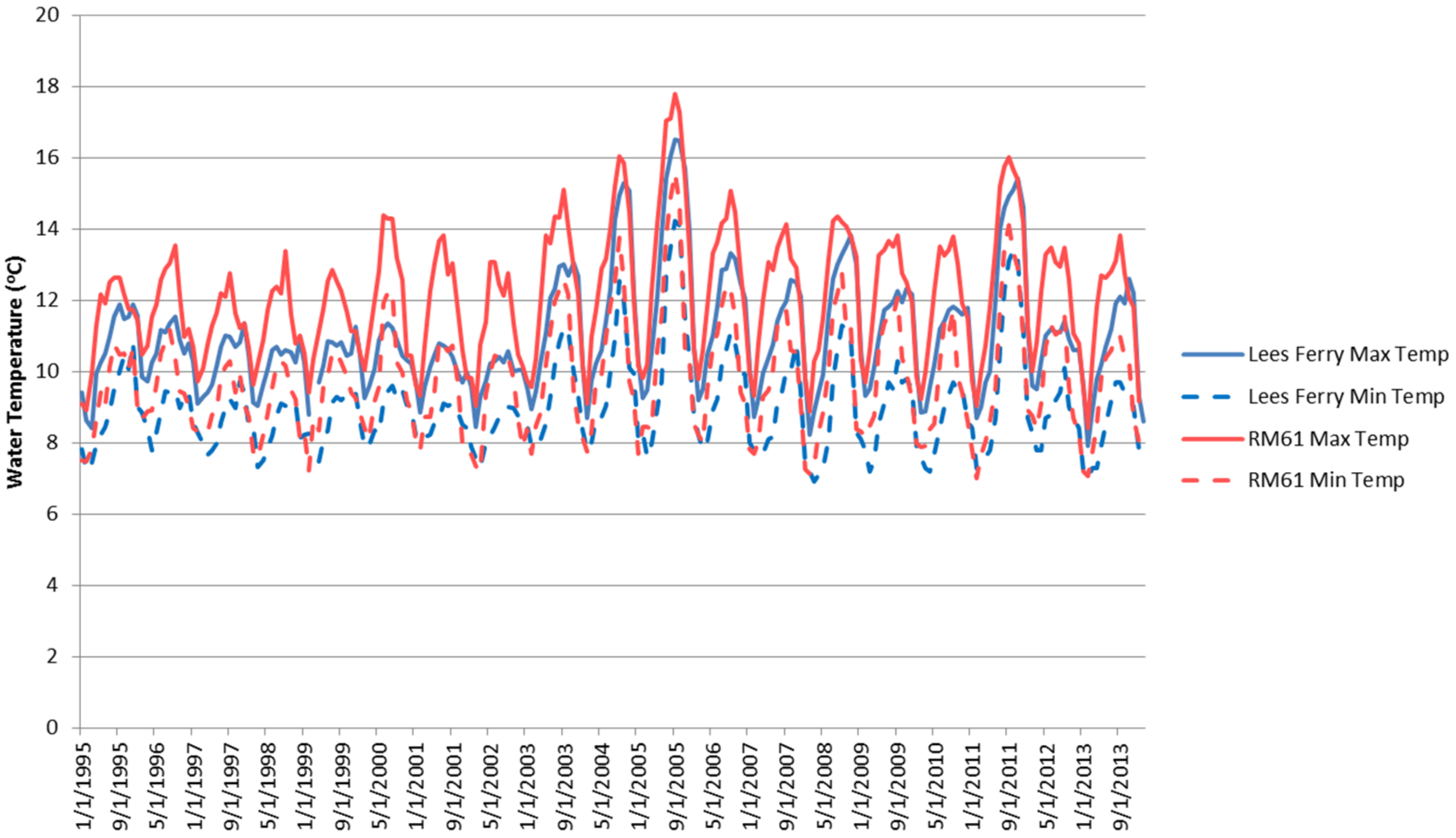

FIGURE 3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence (RM 61), 1995 to Present (Source: USGS 2014b)

yaal tii (Talking God) that they would be able to stay within the Little Colorado River or Little Colorado River Confluence after she was cast out for stealing Talking God's grandchild.

Razorback Sucker

The razorback sucker is a large river sucker (Catostomidae) endemic to the Colorado River system. It is a large fish, with adults reaching lengths up to 3 ft and weighing as much as 13 lb (FWS 2002a), and may live 40 years or more (AZGFD 2002a).

Distribution and Abundance. The razorback sucker was listed as endangered in 1991 (56 FR 54957). The species is endemic to large rivers of the Colorado River Basin from Wyoming to Mexico. Currently, it occurs in the Green River, upper Colorado River, and San Juan River subbasins; the lower Colorado River between Lake Havasu and Davis Dam; Lake Mead and Lake Mohave; and tributaries of the Gila River subbasin (FWS 2002a), and Lake Powell (Francis et al. 2015). The largest remaining wild-spawned population was in Lake Mohave (Marsh et al. 2003); however, the wild fish have died from old age and the population is being supported by rearing of wild-spawned larvae in hatcheries and release of those fish to the reservoir. Within the Grand Canyon, this species historically occurred in the Colorado River from Lake Mead into Maxson Canyon (RM 252.5), with several documented captures at the Little Colorado River inflow in 1989 and 1990, and from the Paria River mouth (in 1963 and 1978, as reported in NPS 2013e). The population in Lake Mead is believed to be self-sustaining, and in 2002 was estimated to consist of about 400 adults (FWS 2002a). More recently (2009–2011), the lakewide population in Lake Mead was estimated to range from 733 to 982 fish (Shattuck et al. 2011).

Until recently, the last razorback sucker collected from the Grand Canyon (RM 39.3) was caught in 1993, and the species was considered extirpated from the Grand Canyon. However, razorback suckers and flannelmouth-razorback sucker hybrids have recently been captured from the western Grand Canyon (Bunch, Makinster et al. 2012; Bunch, Osterhoudt et al. 2012; Rogowski and Wolters 2014; Rogowski, Wolters, et al. 2015). Four fish that were sonic-tagged in Lake Mead in 2010 and 2011 were detected in the spring and summer of 2012 in GCNP up to Quartermaster Canyon (RM 260) (Kegerries and Albrecht 2012, as cited in NPS 2013e). An additional untagged adult razorback sucker was captured in GCNP near Spencer Creek (RM 246) in October 2012 (Bunch, Osterhoudt, et al. 2012), and another adult was collected in late 2013 (GCMRC 2014). Recent sampling of channel margin habitats has also documented razorback sucker larvae as far upstream as RM 179 (just upstream of Lava Falls), indicating that spawning is occurring in the mainstem river in the western Grand Canyon (Albrecht et al. 2014 [462 larvae]; Kegerries et al. 2015 [81 larvae]). Adult razorback suckers have also recently been located as far upstream as RM 184.4 near Lava Falls, and numerous adults have been documented in the western Grand Canyon, indicating that the species utilizes the Colorado River above the Lake Mead inflow area more than previously thought (Albrecht et al. 2014).

Habitat. The razorback sucker uses a variety of habitats, ranging from mainstream channels to slow backwaters of medium and large streams and rivers (AZGFD 2002a). In rivers, habitat requirements of adults in spring include deep runs, eddies, backwaters, and flooded off-channel areas; in summer, runs and pools, often in shallow water associated with submerged sandbars; and in winter, low-velocity runs, pools, and eddies (FWS 2002a). In reservoirs, adults prefer areas with water depths of 3 ft or more over sand, mud, or gravel substrates. Young require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs (FWS 2002a). Recent captures of larval razorback sucker in the western Grand Canyon found the highest density of larvae in isolated pools, which composed less than 2% of all habitat sampled (Albrecht et al. 2014). Similar results were found in 2015, when the highest catch of larval razorback sucker was found in isolated pools, followed by backwaters, which composed 2.1% and 9.1% of habitats sampled, respectively (Kegerries et al. 2015). Critical habitat was designated for this species in 1994, and includes the Colorado River and its 100-year floodplain from the confluence of the Paria River downstream to Hoover Dam (a distance of about 500 mi), including Lake Mead to full pool elevation (59 FR 13374).

Life History. Both adults and immature fish are omnivorous, feeding on algae, zooplankton, and aquatic insect larvae. In Lake Mohave, their diet has been reported to be dominated by zooplankton, diatoms, filamentous algae, and detritus (Marsh 1987).

Razorback suckers exhibit relatively fast growth the first 5 to 7 years of life, after which growth slows and possibly stops (AZGFD 2002a). Both sexes are sexually mature by age 4. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and at water temperatures typically greater than 14°C (57°F) (FWS 2002a). In reservoirs, spawning occurs over rocky shoals and shorelines. Temperatures for spawning, egg incubation, and growth of this species range from 14 to 25°C (57 to 77°F) (Figure 3.5-1). Hatching success is temperature dependent, with complete mortality occurring at temperatures less than 10°C (50°F); optimum temperatures for adults are around 22–25°C (72–77°F) (AZGFD 2002a). Based on back-calculation from the dates of larval collection, Kegerries et al. (2015) estimated that the onset of spawning in the Grand Canyon was in mid-February when average daily water temperatures were between 10 and 12°C (50 and 54°F). Spawning appeared to peak toward the end of March when water temperatures ranged from 12–14°C (54–57°F), although the entire spawning period was estimated to range from mid-February to July (Kegerries et al. 2015).

Historically, this species exhibited upstream migrations in spring for spawning, although current populations include groups that are sedentary and others that move extensively (Minckley et al. 1991). Adults in the Green River subbasin have been reported to move as much as 62 mi to specific areas to spawn (Tyus and Karp 1990). In Lake Mohave, individuals have been reported to move 12 to 19 mi between spring spawning and summer use areas (Mueller et al. 2000). Kegerries et al. (2015) reported that sonic-tagged razorback sucker either stayed near spawning areas or moved up to 361 km (224 mi) within the western Grand Canyon, the Colorado River inflow to Lake Mead, and throughout Lake Mead.

Factors Affecting Distribution and Abundance in the Grand Canyon. The decline of the razorback sucker throughout its range has been attributed primarily to habitat loss due to dam construction, loss of spawning and nursery habitats as a result of diking and dam operations, and alteration of flow hydrology (AZGFD 2002a). For example, the 80% reduction in the historical distribution of this species has been attributed to the construction of Hoover, Parker, Davis, and Glen Canyon Dams on the Colorado River and Flaming Gorge Dam on the Green River (Valdez et al. 2012). In addition, competition with and predation by nonnative fishes have also been identified as important factors in the decline of this species (Minckley et al. 1991; FWS 2002a). In the Grand Canyon, the decline of native fish, including razorback sucker, has been attributed in large part to an increased diversity and abundance of nonnative fishes along with the effects of Glen Canyon Dam on water temperatures, flow, and sediment (Gloss and Coggins 2005).

As described above, recent efforts to better understand the use of the western Grand Canyon by razorback sucker has revealed that the species is more widespread there than previously thought, occupies and spawns in the river from at least Lava Falls to throughout Lake Mead, and maintains a reproducing population in the project area (Albrecht et al. 2014; Kegerries et al. 2015). Currently, there is little information on the habitat use and life history needs for the species in the Grand Canyon and Lake Mead. Additional research and monitoring are needed to better understand the management implications for recovery of razorback sucker in this reach of its range (Albrecht et al. 2014).

Bluehead Sucker

The bluehead sucker is a member of the Catostomidae family. Adults may reach 12 to 18 in. in total length in large rivers but may be smaller in smaller tributaries; they may live from 6 to 8 years to as many as 20 years (Sigler and Sigler 1987; Bezzerides and Bestgen 2002; AZGFD 2003a). This species has been reported to be as large as 20 in. long in the mainstem Colorado River in Grand Canyon, with tributary fish being smaller (AZGFD 2003a). A related subspecies, the Zuni bluehead sucker, occurs in the headwaters of the Little Colorado River along with bluehead suckers that are the same subspecies as those that occur in the mainstem Colorado River (AZGFD 2002b).

Distribution and Abundance. Bluehead sucker populations are declining throughout the species' historic range, and the species has been identified as an AZ-SGCN (AZGFD 2012). The bluehead sucker is included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a). In the Colorado River Basin, this species is found in the Colorado River and its tributaries from Lake Mead upstream into Arizona, Colorado, New Mexico, Utah, and Wyoming. This species is also found in the Snake River (Idaho and Wyoming), the Bear River (Idaho and Utah), and Weber River (Utah and Wyoming) drainages (Bezzerides and Bestgen 2002; AZGFD 2003a).

Within the Grand Canyon, the bluehead sucker occurs in the Colorado River mainstem and its tributaries, including the Little Colorado River, Clear Creek, Bright Angel Creek, Kanab

Creek, and Havasu Creek (Rinne and Magana 2002; AZGFD 2003a; Ptacek et al. 2005; NPS 2013e), and prior to 2014, in Shinumo Creek (Healy et al. 2014). Annual fish monitoring conducted between 2000 and 2009 in the Colorado River between Glen Canyon Dam and the inflow to Lake Mead show the bluehead sucker to be present in all reaches of the river (Makinster et al. 2010). This species is very rare in the upper sections of GCNP and increases in number near the Little Colorado River inflow and downstream (Bunch, Makinster et al. 2012; Bunch, Osterhoudt et al. 2012).

Abundance estimates using monitoring data and Age-Structured Mark-Recapture (ASMR) models show the abundance of age-1 (juvenile) bluehead suckers in the Grand Canyon declined from 1990 to 1995, increased from 1995 to 2003, and then declined through 2009 (Walters et al. 2012). Similar estimates for age-4 (adult) fish show abundance began increasing from the late 1990s until 2005 or 2006, after which abundance also declined. The estimated abundance of age-1 bluehead sucker has ranged from 1,000 or less to as many as 60,000 fish between 2000 and 2009 (Walters et al. 2012). Estimated abundance of age-4+ adults during this same period ranged from about 5,000 to as many as 75,000 fish. Although the bluehead sucker was likely extirpated from Shinumo Creek following fires and flooding in 2014 (Healy et al. 2014), relatively high numbers of individuals remain in the lower Colorado River between Lava Falls Rapid (RM 179) and Lake Mead (Bunch, Makinster, et al. 2012; Bunch, Osterhoudt et al. 2012). Recent sampling of the larval fish community in the western Grand Canyon between Lava Falls and Pearce Ferry collected bluehead sucker larvae throughout the study area (Albrecht et al. 2014). In this study area, the bluehead sucker was the most abundant species in the larval fish community, composing almost 40% of the total catch.

Habitat. The bluehead sucker typically inhabits large streams and may also occur in smaller streams and creeks (Sigler and Sigler 1987; AZGFD 2003a). Riverine habitats may range from cold (12°C [54°F]), clear streams to warm (28°C [82°F]), very turbid rivers. Large adults live in deep water (6 to 10 ft), while juveniles use shallower, lower velocity habitats (Bezzerides and Bestgen 2002). In clear streams, the bluehead sucker stays in deep pools and eddies during the day and moves to shallower habitats (e.g., riffles, tributary mouths) to feed at night, while in turbid waters they may use shallow areas throughout the day (Beyers et al. 2001; AZGFD 2003a). In the Grand Canyon, larval and young bluehead suckers inhabit backwater areas and other near-shore low-velocity habitats such as eddies, embayments, and isolated pools (Childs et al. 1998; AZGFD 2003a; Albrecht et al. 2014).

Life History. The bluehead sucker is an omnivorous benthic forager. It feeds by scraping algae, invertebrates, and other organic and inorganic materials off rocks and other hard surfaces (Ptacek et al. 2005). Larvae drift to backwaters and other areas of low current where they feed on diatoms, zooplankton, and dipteran larvae.

In the lower Colorado River, this species spawns in spring and summer after water temperatures exceed 16°C (61°F). Spawning in Grand Canyon tributaries occurs mid-March through June in water depths ranging from a few inches to more than 3 ft and at temperatures of 16 to 20°C (61 to 68°F) over gravel-sand and gravel-cobble substrates (AZGFD 2003a;

NPS 2013e). In Kanab Creek, spawning has been reported to occur at temperatures of 18.2–24.6°C (64.8–76.3°F) (Maddux and Kepner 1988). Smaller tributaries may provide nursery grounds for populations of large adjacent rivers (Rinne and Magana 2002).

Factors Affecting Distribution and Abundance in the Grand Canyon. As with the humpback chub, decreases in distribution and abundance of the bluehead sucker throughout its range, as well as in portions of the Colorado River and its tributaries below Glen Canyon Dam, have been attributed to two main factors: (1) habitat degradation through loss, modification, and/or fragmentation and (2) interactions with nonnative species (Gloss and Coggins 2005; Ptacek et al. 2005). Disturbance related to fire and flooding may also influence bluehead sucker distribution in tributaries. The construction and operation of Glen Canyon Dam has altered downstream temperature and flow regimes. Cold tailwaters below dams are below temperatures needed for spawning and recruitment (Rinne and Magana 2002; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates coincided with brood years 2003 and 2004, when there was a sudden increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012).

The introduction of nonnative fish has increased competition with and predation on bluehead sucker (AZGFD 2003a; Ptacek et al. 2005). Large nonnative predators such as channel catfish and trout, mid-sized fish like sunfishes, and even smaller nonnative minnows may all prey on one or more life stages of the bluehead sucker (Rinne and Magana 2002; Ptacek et al. 2005; Yard et al. 2011).

3.5.2.2 Other Native Species

Two other native fish species occur in the affected area of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead—flannelmouth sucker and speckled dace (Table 3.5-1). Both speckled dace and flannelmouth sucker are identified as AZ-SGCN (AZGFD 2012). In addition, the flannelmouth sucker is included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a). The flannelmouth sucker and speckled dace are discussed below.

Flannelmouth Sucker

The flannelmouth sucker is member of the sucker family (Catostomidae). It is a relatively large fish, with a maximum total length of greater than 2 ft and a maximum weight exceeding 3 lb (AZGFD 2001b; Rees et al. 2005). It is a long-lived species, living as long as 30 years (AZGFD 2001b).

Distribution and Abundance. Historically, the flannelmouth sucker ranged throughout the Colorado River Basin, in moderate to large rivers in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming (Bezzerides and Bestgen 2002; Rees et al. 2005). Within the Grand Canyon, this species may be found in the mainstem Colorado River and its tributaries including the Little Colorado and Paria Rivers and Shinumo, Bright Angel, Kanab, and Havasu Creeks (Douglas and Marsh 1998; Weiss 1993; AZGFD 2001b; Bezzerides and Bestgen 2002). In contrast to bluehead sucker, flannelmouth sucker are only found below the barrier falls in Shinumo and Havasu Creeks. Annual monitoring conducted between 2000 and 2009 found the flannelmouth sucker to be present in all reaches of the river between Lees Ferry and the inflow to Lake Mead (Makinster et al. 2010). Abundance, across all reaches and measured as catch-per-unit-effort, has been increasing since 2000, especially since about 2004 (Makinster et al. 2010). However, abundance has been decreasing within individual reaches between RM 0 and RM 179 since about 2005, but increasing downstream of RM 179. Recent surveys of the small-bodied and larval fish communities in the western Grand Canyon (Lava Falls to Pearce Ferry) found flannelmouth sucker to be present throughout the reach, accounting for over 38% of the total larval catch in this area (Albrecht et al. 2014).

Abundance estimates using monitoring data and ASMR models show an increase in the abundance of age-1 (juvenile) and age-4 (adult) flannelmouth suckers in the Grand Canyon between 2000 and 2008 (Walters et al. 2012). Abundance of age-1 flannelmouth sucker increased from about 2,500 in 2000 to about 10,000 in 2008, while abundance of age 4+ adults increased from about 10,000 to about 25,000 for this same period (Walters et al. 2012). Other abundance estimates based on electrofishing catch-per-unit-effort for this same time period showed an increase in abundance from less than 1,000 in 2000 to about 12,000 in 2009, while the estimated abundance of age-4+ adults increased from about 2,500 in 2001 to about 31,000 in 2009 (Walters et al. 2012).

Habitat. This species prefers large to moderately large rivers. Adults may prefer deep water when not feeding (Rinne and Minckley 1991), while larvae and young are often associated with shallow, slow-moving near-shore areas such as backwaters and shoreline areas of slow runs or pools (AZGFD 2001b; Rees et al. 2005). Although it is a riverine species, in the upper Colorado River Basin the flannelmouth sucker has been collected from Flaming Gorge and Fontenelle Reservoirs. In the Colorado River in the Grand Canyon, subadults are found in eddies and runs over sand bottoms. In the Little Colorado River, adult and juvenile flannelmouth suckers use low-velocity, near-shore habitats with large amounts of cover during the daylight, and their use of faster, more exposed mid-channel habitats increases at night (Gorman 1994). Juveniles and adults may be considered habitat generalists and can be found using pool, run, and eddy habitats. Recent surveys of larval flannelmouth sucker in the western Grand Canyon (Lava Falls to Pearce Ferry) found the highest abundance of larvae in embayments, isolated pools, backwaters, and other low-velocity habitats (Albrecht et al. 2014).

Life History. The flannelmouth sucker is an omnivorous benthic feeder, foraging on invertebrates, algae, plant seeds, and organic and inorganic debris (Bezzerides and Bestgen 2002; Rees et al. 2005; Seegert et al. 2014). Larvae feed primarily on aquatic invertebrates, crustaceans, and organic debris (Childs et al. 1998). As they become juveniles and adults, their diet shifts and becomes primarily composed of benthic matter including organic debris, algae, and aquatic invertebrates (Rees et al. 2005; Seegert et al. 2014).

This species has been reported to prefer water temperatures ranging from 10 to 27°C (50 to 81°F), and is most common at about 26°C (79°F) (Sublette et al. 1990). Water temperatures reported during spawning activity range from 6 to 18.5°C (43 to 65°F), but are usually above 14°C (57.2°F) (Bezzerides and Bestgen 2002). In the lower Colorado River Basin, flannelmouth sucker spawning typically occurs in March and April (Bezzerides and Bestgen 2002). Water temperature has been suggested as a primary cue for spawning in other parts of this species range, but it does not appear to provide a spawning cue in the Grand Canyon where relatively synchronized spawning has been reported among sucker stocks from creeks with different temperature and flow regimes (Weiss 1993; Weiss et al. 1998). In the Paria River, the timing of spawning has been correlated with the receding limb of the hydrograph (Weiss 1993).

In the Grand Canyon, flannelmouth suckers apparently spawn at only a limited number of tributaries, and fish may move considerable distances to reach spawning sites (Douglas and Marsh 1998; Weiss et al. 1998; Douglas and Douglas 2000). Tributary spawning in the Grand Canyon may be timed to take advantage of warm, ponded conditions at tributary mouths that occur during high flows in the mainstem Colorado River (Bezzerides and Bestgen 2002).

Body condition of flannelmouth sucker is variable throughout the Grand Canyon, but is greatest at intermediate distances from Glen Canyon Dam, possibly because of the increased number of warmwater tributaries in this reach (Paukert and Rogers 2004). Mean condition peaks during the prespawn and spawning periods and is lowest in summer and fall (McKinney et al. 1999; Paukert and Rogers 2004). Sucker condition in September was positively correlated with Glen Canyon discharge during summer (June–August), possibly due to an increased euphotic zone and greater macroinvertebrate abundance observed during higher water flows (Paukert and Rogers 2004).

Factors Affecting Distribution and Abundance in the Grand Canyon. Flannelmouth sucker populations have declined throughout the species' historic range; in the lower Colorado River, this decline has been attributed primarily to flow manipulation and water development projects (Rees et al. 2005). Coldwater releases from Glen Canyon Dam have altered the thermal regime of the main channel of the Colorado River, which for larvae may result in slow growth, delayed transition to the juvenile stage, and possibly higher mortality (Rees et al. 2005).

In the cold tailwaters below Glen Canyon Dam, water temperatures (8 to 12°C [46 to 54°F]) are at the lower end of or below those needed for spawning and recruitment of flannelmouth suckers; even though water temperatures do warm downstream, the cold summer water temperatures have been suggested as a major factor limiting survival of YOY, recruitment, and condition of this species in the main channel (Thieme et al. 2001; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates were for 2003 and 2004, when there was a sudden increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012). Paukert and Rogers (2004) reported post-spawn condition of flannelmouth sucker below Glen Canyon Dam to be variable, but were typically greatest in the vicinity of warmwater tributaries such as the Paria River, the Little Colorado River, and Bright Angel Creek.

The flannelmouth sucker in the Grand Canyon may also be experiencing competition with and predation by nonnative species that are in the system (Rees et al. 2005). Potential competitors include species such as the channel catfish and the common carp. Potential predators include rainbow and brown trout and red shiner. Rainbow and brown trout diet sampling found enough juvenile flannelmouth suckers in trout stomachs to account for as much as 50% of the estimated annual mortality rates of juveniles (Yard et al. 2011; Walters et al. 2012). The ability of flannelmouth sucker to escape trout predation is also inhibited by colder water temperatures (Ward and Bonar 2003).

Speckled Dace

The speckled dace is native to the western United States and is one of eight species in the genus *Rhinichthys*. It is a small fish, typically less than 76 mm in length, and has a relatively short lifespan of about 3 years (Sigler and Sigler 1987).

Distribution and Abundance. This species is native to all major western drainages from the Columbia and Colorado Rivers south to Mexico (AZGFD 2002c). Within the Grand Canyon, this species occurs within the mainstem Colorado River and its tributaries, including the Little Colorado River (Robinson et al. 1995; Ward and Persons 2006; Makinster et al. 2010). Long-term fish monitoring of the Colorado River below Glen Canyon Dam since 2000 shows the speckled dace to be the third most common fish species (and most common native species) in the river between Glen Canyon Dam and the Lake Mead inflow, and it was captured most commonly in the western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010).

Habitat. The speckled dace may be found in a variety of habitats, ranging from cold, fast-flowing mountain streams to warm, intermittent desert streams and springs. Where found, it occurs in rocky runs, riffles, and pools of headwater streams, creeks, and small to medium rivers, typically in waters with depths less than 1.6 ft (AZGFD 2002c); it rarely occurs in lakes (Page and Burr 1991).

Life History. The speckled dace is an omnivorous bottom feeder, feeding primarily on insect larvae and other invertebrates, as well as algae and fish eggs (Seegert et al. 2014). Its young are mid-water plankton feeders (Sigler and Sigler 1987). This dace spawns twice, once in spring and again in late summer (AZGFD 2002c). Spawning occurs over gravel in areas prepared by the male.

Factors Affecting Distribution and Abundance in the Grand Canyon. The speckled dace is a widespread and abundant species in western North America (AZGFD 2002c). Although this species is the most widely distributed and abundant native fish species in the Grand Canyon ecosystem, its abundance and distribution could be affected by many of the same factors that affect the abundance and distribution of the other native fish in the ecosystem, namely altered temperature, flow, and sediment regimes and predation by nonnative fish (AZGFD 2002c; Gloss and Coggins 2005).

3.5.3 Nonnative Fish

As many as 25 nonnative species of fish have been reported with some regularity from Lakes Powell and Mead and the Colorado River and its tributaries between these reservoirs (Valdez and Speas 2007; Coggins et al. 2011; Reclamation 2011e; Table 3.5-2). Most of these introduced species are native to other basins in North America but not the Colorado River Basin, and a few are species from outside North America. These fish occur in the Grand Canyon as a result of intentional and unintentional introductions, especially into Lakes Powell and Mead. A number of species were stocked as game fish and others as forage fish for the stocked game fish. Among these nonnative species, three are largely restricted to Lake Powell and/or Lake Mead, and occur in the Colorado River and its tributaries below Glen Canyon Dam only occasionally; these species are black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and gizzard shad (*Dorosoma cepedianum*) (Table 3.5-2). Another four species—northern pike (*Esox lucius*), threadfin shad (*Dorosoma petenense*), rock bass (*Ambloplites rupestris*), and yellow perch (*Perca flavescens*)—are largely restricted to the upper Little Colorado River watershed (Ward and Persons 2006; Valdez and Speas 2007). The remaining 18 species have been reported from the mainstem Colorado River and/or its tributaries between Glen Canyon Dam and the inflow to Lake Mead. New introductions of nonnative fish species continue to be documented throughout the Colorado River Basin, and new introductions are likely to occur (Martinez et al. 2014).

Common nonnative fish species in Lake Powell include striped bass, smallmouth and largemouth bass, walleye (*Sander vitreus*), bluegill, green sunfish (*Lepomis cyanellus*), common carp, and channel catfish. Species that occur in the reservoir, but that are mainly associated with tributaries and inflow areas, include fathead minnow, mosquitofish (*Gambusia affinis*), red shiner, and plains killifish (NPS 1996; Reclamation 2007a). Largemouth bass (*Micropterus salmoides*) and black crappie populations were stocked initially and, following successful establishment, these were the principal target species in the sport fisheries for many years. Both species have declined in recent years due to a lack of habitat structure for young fish. Filling and fluctuation of the reservoir resulted in changing habitat that eliminated most of the vegetation favored by many species (Reclamation 2007a). Smallmouth bass (*Micropterus dolomieu*) and striped bass (*Morone saxatilis*) were introduced following these changes in habitat structure and are presently the dominant predators in the reservoir (Reclamation 2007a). Threadfin shad were introduced to provide an additional forage base and quickly became the predominant prey species (NPS 1996). Gizzard shad were accidentally introduced into Morgan Reservoir in the San Juan River drainage in 1996 and subsequently proliferated in Lake Powell (Mueller and Brooks 2004; Vatland and Budy 2007).

TABLE 3.5-2 Nonnative Fish Found in the Colorado River through Glen and Grand Canyons

Species	Native Origin	Occurrence in Project Area
Coldwater Species		
Rainbow trout (*Oncorhynchus mykiss*)	North America	Colorado River from Glen Canyon Dam to Havasu Creek; abundant from Glen Canyon Dam to Lees Ferry; abundance decreases through Marble Canyon to the confluence with the Little Colorado River, although substantial numbers may still be present in some locations in some years; locally abundant at the Little Colorado River confluence and some locations through Grand Canyon in some years.
Brown trout (*Salmo trutta*)	Europe	Colorado River from Glen Canyon Dam to Kanab Creek; locally abundant near confluence with Bright Angel Creek, the Little Colorado River, and some other tributaries.
Warmwater Species		
Black bullhead (*Ictalurus melas*)	North America	Lake Powell, Lake Mead; Colorado River at the Little Colorado River; Colorado River downstream of Diamond Creek; generally absent from Glen Canyon, rare in Marble Canyon, and locally common in some areas of the Grand Canyon.
Yellow bullhead (*Ameiurus natalis*)	North America	Colorado River downstream of the Little Colorado River to Lake Mead; Little Colorado River, abundance presumed similar to that of black bullhead.
Channel catfish (*Ictalurus punctatus*)	North America	Lake Powell, Lake Mead, Colorado River from Marble Canyon to Lake Mead; generally absent from Glen Canyon, rare in Marble Canyon, and numerous in the Grand Canyon.
Green sunfish (*Lepomis cyanellus*)	North America	Lake Powell; Lake Mead; Kanab Creek; discovered in abundance in a slough located just downstream of Glen Canyon Dam in 2015 (eradication efforts conducted); generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Bluegill (*Lepomis macrochirus*)	North America	Lake Powell, Lake Mead; abundance presumed similar to that identified for green sunfish.
Largemouth bass (*Micropterus salmoides*)	North America	Lake Powell; Kanab Creek; Lake Mead to Maxson Canyon; generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Smallmouth bass (*Micropterus dolomieu*)	North America	Lake Powell; Colorado River at the Little Colorado River, below Glen Canyon Dam; rare from Glen Canyon through the Grand Canyon.

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Rock bass (*Ambloplites rupestris*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Black crappie (*Pomoxis nigromaculatus*)	North America	Lake Powell; Lake Mead; generally absent from Glen Canyon, Marble Canyon, and Grand Canyon.
Fathead minnow (*Pimephales promelas*)	North America	Colorado River from the Paria River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Golden shiner (*Notemigonus crysoleucus*)	North America	Colorado River from Glen Canyon to Separation Canyon; Kanab Creek; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Redside shiner (*Richardsonius balteatus*)	North America	Lake Powell; Colorado River at the Little Colorado River; generally rare throughout Glen Canyon, Marble Canyon, and Grand Canyon.
Red shiner (*Cyprinella lutrensis*)	North America	Colorado River at the Little Colorado River; Colorado River from Bridge Canyon to Lake Mead.
Common carp (*Cyprinus carpio*)	Eurasia	Lake Powell, Lake Mead, Colorado River from Glen Canyon Dam to Lake Mead.
Goldfish (*Carassius auratus*)	Eurasia	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Plains killifish (*Fundulus zebrinus*)	North America	Little Colorado River; Colorado River from Little Colorado River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Mosquitofish (*Gambusia affinis*)	North America	Lake Powell; Colorado River from Separation Canyon to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Walleye (*Stizostedion vitreum*)	North America	Lake Powell; Colorado River from Lava Falls to Lake Mead; generally rare throughout Glen Canyon (but consistently observed during electrofishing surveys), Marble Canyon, and the Grand Canyon.
Yellow perch (*Perca flavesens*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Striped bass (*Morone saxatilis*)	North America	Lake Powell; Colorado River from Havasu Creek to Lake Mead; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Northern pike (*Esox lucius*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Gizzard shad (*Dorosoma cepedianum*)	North America	Lake Powell; generally absent from Glen Canyon, Marble Canyon, and the Grand Canyon.
Threadfin shad (*Dorosoma petenense*)	North America	Lake Powell; Lake Mead; Colorado River from Glen Canyon to Separation Canyon; Upper Little Colorado River watershed; generally rare in Glen Canyon, Marble Canyon, and the Grand Canyon.

Sources: Holden and Stalnaker (1975); Gloss and Coggins (2005); Valdez and Speas (2007); Coggins et al. (2011); Reclamation (2011e).

Common nonnative fish species present in Lake Mead include striped bass, largemouth bass, red shiner, common carp, threadfin shad, and mosquitofish. The sport fishery in Lake Mead is primarily for striped bass and largemouth bass, although catfish species and hatchery-reared rainbow trout are also targeted by some anglers (Reclamation 2007a). As with Lake Powell, nonnative fish species present in Lake Mead were established through intentional and unintentional introductions.

The coldwater releases from Glen Canyon Dam result in river temperatures that are substantially cooler in summer and fall than those that occurred prior to construction of the dam. During periods of the year with warmer air temperatures, water temperatures gradually warm with downstream distance from the dam. These low water temperatures generally do not support native fish reproduction in the mainstem, and largely restrict native fish spawning to warmwater tributaries (Vernieu et al. 2005; Kennedy and Ralston 2011). Cold water similarly limits growth rates and reproduction for many of the warmwater nonnative fishes present in the mainstem (Clarkson and Childs 2000). However, low reservoir elevations since 2003 have resulted in release temperatures as high as 16°C (61°F) in some years. Table 3.5-3 presents average recorded water temperatures for various locations downstream of Glen Canyon Dam from 2006 to 2009.

The nonnative fish community changes in response to temperature and turbidity gradients in the mainstem (Makinster et al. 2010). In general, the reaches of the river just downstream of Glen Canyon Dam are dominated by coldwater nonnative species while downstream reaches through the Grand Canyon are currently dominated by native species, although substantial

TABLE 3.5-3 Mean Water Temperature and Turbidity for Selected Sites in the Colorado River Mainstem from 2006 to 2009

Mainstem River Location	Mean Water Temperature (°C±SD [°F±SD])	Turbidity (NTU)[a]
Lees Ferry, RM 0	10.4 ±1.5 (50.7 ±2.7)	2 ±10.5
Fence Fault, RM 30	10.7 ±1.5 (51.3 ±2.7)	50 ±347
Upstream Little Colorado River Confluence, RM 61	11.3 ±1.7 (52.3 ±3.0)	71 ±478
Phantom Ranch, RM 88	12.0 ±2 (53.5 ±3.6)	225 ±672
Diamond Creek Vicinity, RM 225	13.8 ±3.1 (56.9 ±5.5)	347 ±1,070

[a] NTU = nephelometric turbidity units. As NTU increases, water clarity decreases.

Source: Kennedy and Ralston (2011).

numbers of warmwater nonnative species are also present (Makinster et al. 2010). The water temperatures in the Glen Canyon reach are suitable (although colder than optimal) for rainbow trout spawning and growth (McKinney, Speas, et al. 2001). In the reach of cool, clear water between the dam and the Little Colorado River, the productivity of the aquatic food web (Section 3.5.1) is driven by microscopic algae (Angradi 1994; Shannon et al. 1994), invertebrate biomass is higher than in reaches farther downstream (Stevens, Shannon, et al. 1997), and rainbow trout (a visual sight feeder) is the dominant fish species (Makinster et al. 2010). As water temperature and turbidity increase downstream of the Little Colorado River confluence, nonnative warmwater fish species such as the common carp, red shiner, and several species of catfish increase in number (Makinster et al. 2010). The warmer water temperatures provide suitable conditions for spawning and growth for many of the warmwater nonnative species, many of which are benthic feeders adapted to foraging in turbid conditions (Gloss and Coggins 2005).

In addition, the annual distribution of nonnative fishes in the lower portions of the Grand Canyon may also be influenced by the elevation of Lake Mead. As the elevation of Lake Mead rises, lake-like conditions suitable for many of the warmwater nonnative fishes will temporarily extend farther upstream into the lower portion of the Grand Canyon.

More detailed information on coldwater and warmwater nonnative fish species is provided in the next two sections.

3.5.3.1 Coldwater Nonnative Species

Brown and rainbow trout make up the coldwater nonnative fish community of the Colorado River between Glen Canyon Dam and the inflow to Lake Mead (Figure 3.5-1). The rainbow trout is common in the Glen Canyon reach and in the mainstem Colorado River between the confluence with the Paria River and the confluence with the Little Colorado River

(Makinster et al. 2010; Reclamation 2011e). Smaller numbers are found associated with tributaries, including Bright Angel Creek, Shinumo Creek, Deer Creek, Tapeats Creek, Kanab Creek, and Havasu Creek (Reclamation 2011e). Brown trout are found primarily in and near Bright Angel Creek, which supports a spawning population (Reclamation 2011e), but they are also found throughout the upper reaches of the river corridor, including in Glen Canyon.

Rainbow Trout

The rainbow trout is very common in the reach of the mainstem Colorado from Glen Canyon Dam to the Paria River, and this population serves as the principal basis for the trout fishery. This species is also found in relatively high abundance in Marble Canyon between the Paria River and the confluence of the Colorado River with the Little Colorado River (Makinster et al. 2010; Reclamation 2011e). Downstream of the Little Colorado River confluence, smaller numbers of rainbow trout are found in localized aggregations associated with some tributaries.

Rainbow trout were initially introduced in the Grand Canyon region through stocking of tributaries such as Bright Angel Creek during the 1920s. Additional introductions of rainbow trout were made downstream of Glen Canyon Dam in 1964 following completion of dam construction. Prior to 1991, the population was maintained through annual stocking, and stocking continued through 1998 (Makinster et al. 2011). Since that time, the Glen Canyon rainbow trout fishery has been maintained through natural reproduction of rainbow trout rather than through stocking, and, with the exception of localized spawning in some downstream tributaries, most of the rainbow trout production in the Colorado River downstream of Glen Canyon Dam occurs within the Glen Canyon reach. Collections of YOY rainbow trout during recent surveys in the vicinity of the Little Colorado River suggest that some successful spawning may be occurring in or near the Little Colorado River. Standardized annual monitoring of the population of rainbow trout in the 15-mi reach of the Colorado River between Glen Canyon Dam and Lees Ferry began in 1991. Based on catches of rainbow trout during annual monitoring surveys, the abundance of rainbow trout in Glen Canyon generally increased over the period from 1991 to 1997, remained at high levels until approximately 2001, and then declined to low levels by 2007 (Figure 3.5-6). From 2008 through 2010, the relative abundance of rainbow trout in the Glen Canyon reach again increased to near historic high levels. Relative abundance reached all-time high levels in water years 2011 and 2012, followed by a decline in water year 2013 consistent with previous high abundance estimates (AZGFD data as reported in GCMRC 2014; Figure 3.5-6).

Rainbow trout recruitment and population size within the Glen Canyon reach appear to be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999; McKinney, Speas, et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman, Kaplinski et al. 2011; Kormon et al. 2012). McKinney et al. (1999) attributed the increase in abundance from 1991 to 1997 to increased minimum flows and reduced fluctuations in daily discharges resulting from implementation of interim flows between 1991 and 1996 and adoption of the current modified low fluctuating flow regime in 1996. The decline in abundance from 2001 to 2007 has been attributed to the combined influence of increased trout metabolic demands

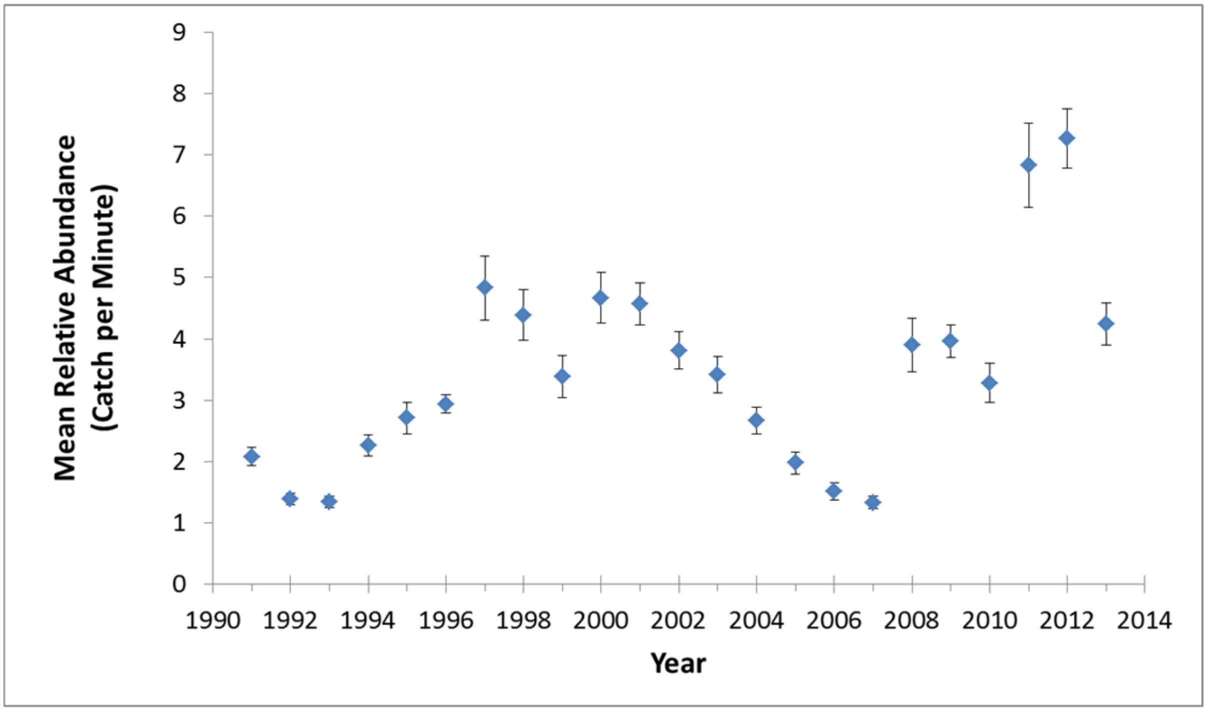

FIGURE 3.5-6 Mean (±2 SE) Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2013 (Source: Persons 2014)

due to warmer water releases from Glen Canyon Dam during that period, together with a static or declining food base, periodic DO deficiencies, and high numbers of the invasive New Zealand mudsnail, which serves as a poor food source (Cross et al. 2011). A similar decline in rainbow trout abundance below the Paria River was observed during the 2001 to 2007 time period (Makinster et al. 2010). Increases in recruitment levels and the levels of trout abundance in the Glen Canyon reach during 2008 and 2009 are believed to be due to improved habitat conditions and survival rates for YOY rainbow trout resulting from the HFE that occurred in March of 2008 (Makinster et al. 2011). Korman et al. (2012) also found that recruitment of rainbow trout in Glen Canyon was positively and strongly correlated with annual flow volume and reduced hourly flow variation, and also that recruitment increased after two of three high-flow releases related to the implementation of equalization flows. The abundance of rainbow trout within the Glen Canyon reach affects the condition (a measure of the weight-length relationship, or "plumpness") of rainbow trout in the population, with the condition generally being inversely related to the relative abundance of rainbow trout within the reach (Makinster et al. 2011). Thus, it has generally been observed that as the relative abundance of trout within the reach increases, the condition of trout within the reach declines; as condition falls lower, it is anticipated that survival and recruitment to the population would be affected.

Rainbow trout in Glen, Marble, and Grand Canyons are considered exposed to whirling disease. Whirling disease infects only salmon and trout species, and is caused by *Myxobolus cerebralis*, a myxozoan parasite introduced to North America from Europe in the 1950s. Whirling disease was initially detected in Glen Canyon in 2007 (Makinster 2007). Twenty-two percent of rainbow trout samples collected from Glen Canyon in 2011 were found to be infected with whirling disease. The presence of whirling disease has raised concerns regarding the potential to spread whirling disease to unaffected waters and watersheds through live removal and relocation of rainbow trout associated with the Nonnative Fish Control Environmental Assessment (EA) (Reclamation 2011e). It is anticipated that there is a low risk of spreading whirling disease as a consequence of conducting experimental floods as part of the High-Flow Experiment EA (Reclamation 2011d; VanderKooi 2012). The parasite is already present downstream from Glen Canyon Dam, and no barriers exist to prevent infected rainbow trout from moving into Marble and Grand Canyons. It is likely that HFEs will result in a decrease in the prevalence and severity of infections through reductions in the abundance of the intermediate host, the oligochaete worm *Tubifex tubifex*, and its preferred habitat of fine sediment and organic matter (VanderKooi 2012).

Because of the potential for trout to compete with and prey on native fish (Gloss and Coggins 2005; Yard et al. 2011; Whiting et al. 2014), the numbers of trout that leave the Glen Canyon reach and move to downstream locations is of potential concern. In particular, there is interest in limiting the numbers of trout that would enter the reach of the Colorado River in the vicinity of the confluence with the Little Colorado River because of the potential for negative effects on the endangered humpback chub population (Gloss and Coggins 2005; Yard et al. 2011). Data suggest that the numbers of trout that emigrate downstream from the Glen Canyon reach may largely be driven by the abundance of trout within the Glen Canyon reach. An increase in rainbow trout in the Little Colorado River reach after 2006 has been attributed to the increased survival and growth of young trout in the Glen Canyon reach following the March 2008 HFE (Wright and Kennedy 2011). The largest increases in trout abundance in both the Glen Canyon reach and the vicinity of the confluence with the Little Colorado River were seen after the 2011 equalization flows (Figure 3.5-6). It has been suggested that the 2008 HFE may have improved conditions for spawning and egg incubation of rainbow trout in the Glen Canyon reach by flushing fine sediment from spawning gravels and may have improved the survival of young trout by increasing the production and availability of invertebrates that serve as food for trout (Korman et al. 2010; Rosi-Marshall et al. 2010; see Section 3.5.1 for background information on the aquatic food base). Modeling conducted by Korman et al. (2012) suggests that 70% or more of the variation in the rates of rainbow trout emigration from the Glen Canyon reach could be explained by variation in recruitment levels in the Glen Canyon reach. Regardless, higher recruitment does not necessarily result in greater levels of emigration and there are years in which recruitment levels in the Glen Canyon reach were relatively high but emigration into Marble Canyon was not (e.g., following the HFE in 2012; Korman et al. 2012). In addition to emigration of trout to the Little Colorado River reach, recent captures of YOY trout upstream of the Little Colorado River confluence suggest that there may be some limited amount of spawning in lower Marble Canyon. Efforts to control nonnative fish in the Little Colorado River reach using flow manipulation to limit recruitment in Glen Canyon and mechanical removal in the Little Colorado River reach itself are described in Section 3.5.3.4.

Brown Trout

As with rainbow trout, brown trout are not native to the Colorado River and were stocked in Grand Canyon in the first half of the 1900s. Brown trout are no longer stocked in the Colorado River downstream of Glen Canyon Dam and are now found primarily in and near Bright Angel Creek, which supports a naturally spawning population (Reclamation 2011e). Unlike rainbow trout, brown trout are not susceptible to infestations of whirling disease. A trout control project, using a combination of a fish weir trap and electrofishing to benefit native species in Bright Angel Creek and endangered humpback chub in the Colorado River, was implemented by the NPS during winters 2006–2007, 2010–2011, 2011–2012, 2012–2013, 2013–2014, and 2014–2015 under the 2006 and 2013 EAs and a Finding of No Significant Impact (FONSI; NPS 2006c, 2013d).

Overall, the abundance (based on electrofishing surveys) of brown trout in the Colorado River between Lees Ferry and Lake Mead declined from 2000 to 2006; abundance may have increased somewhat between 2007 and 2009 (Figure 3.5-7; Makinster et al. 2010). Because spawning by brown trout in the Grand Canyon occurs primarily in tributaries (e.g., Bright Angel Creek and Shinumo Creek), recruitment rates may be less affected by conditions in the mainstem than recruitment rates of rainbow trout. However, recent increases in brown trout recruitment in 2014–2015 have occurred in the Lees Ferry reach of the Colorado River in Glen Canyon (Stewart 2016). Brown trout were observed to be spawning near the 4-mi bar in Glen Canyon during the fall of 2014, and an increase in age-1 brown trout, likely as a result of spawning and recruitment in 2014, was observed in 2015 (Korman et al. 2015). Spawning of brown trout was also observed during October and November of 2015 near the 4-mi bar in Glen Canyon (Korman et al. 2015). It is unclear if flow operations, including recent fall HFEs, caused an increase in brown trout in recent years.

Some brown trout captured in Bright Angel Creek were originally tagged in other parts of the Colorado River, as much as 25 mi from Bright Angel Creek (Reclamation 2011e). Small numbers of brown trout are also found in other locations within the Grand Canyon, including in the vicinity of the Little Colorado River confluence and in Glen Canyon. An indication of the relative abundance of brown and rainbow trout in the vicinity of the Little Colorado River is provided by the numbers captured using electrofishing during trout removal efforts. Of 23,000 nonnative fish captured as part of removal efforts from 2003 to 2006, 19,020 were rainbow trout and 470 were brown trout (Reclamation 2011e). All brown trout captured during these efforts were removed from the river.

Although the number of brown trout is small relative to rainbow trout, Yard et al. (2011) found that on an individual basis, the brown trout is a more active predator on native fish in the Colorado River than rainbow trout (see Section 3.5.3.3). Yard et al. (2011) also found a significant positive correlation between temperature and the levels of piscivory by brown trout. Other studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout in different ways. For example, while the incidence of predation attempts increased, the success of predation of rainbow trout on YOY humpback chub decreased as temperatures increased from 10°C to 20°C (50°F to 68°F)

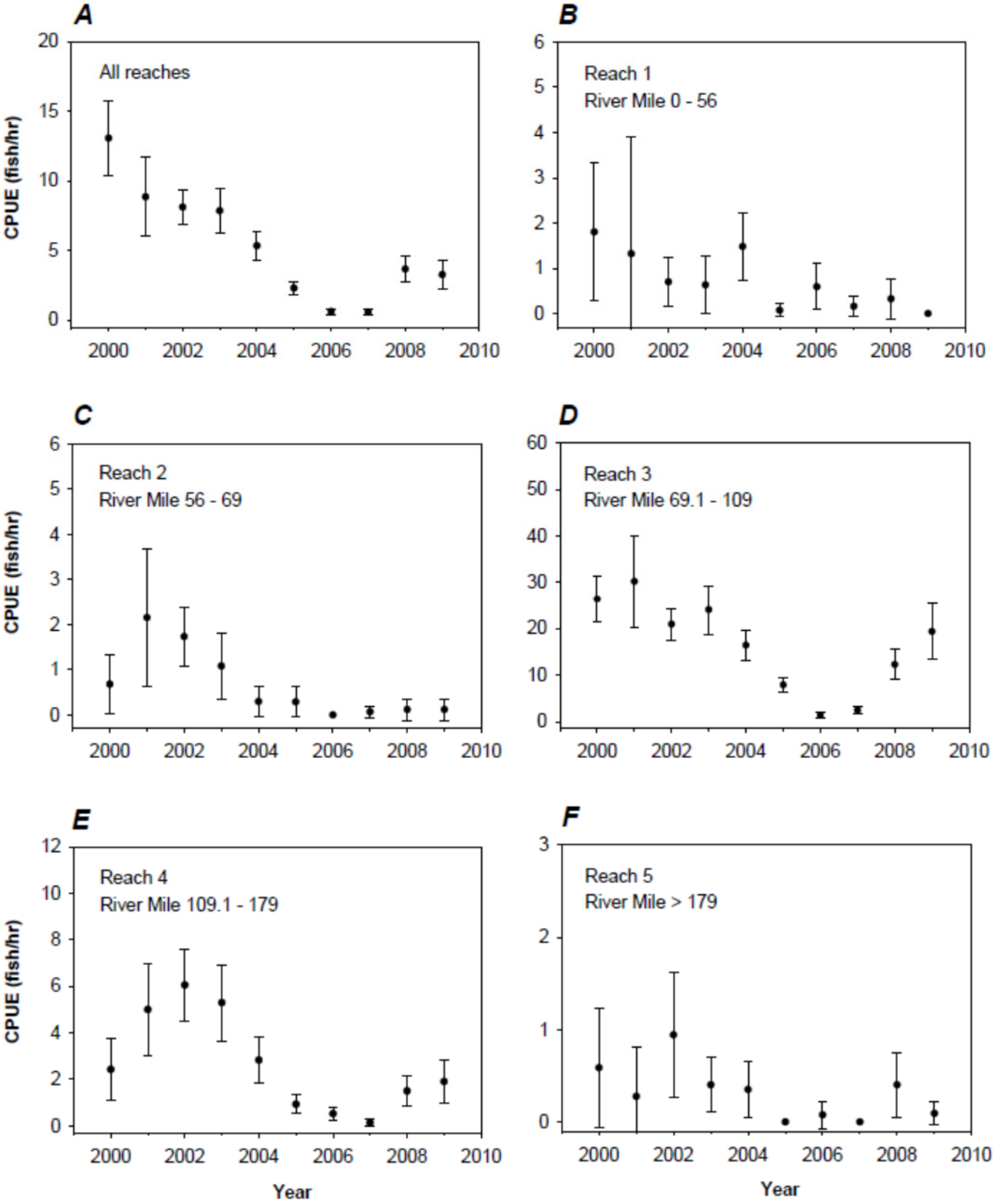

FIGURE 3.5-7 Mean (±2 SE) Electrofishing Catch Rates of Brown Trout in the Colorado River between Lees Ferry and Lake Mead, 2000–2009 (Note differences in scale among graphs A–F.) (Source: Makinster et al. 2010)

(Ward 2011). In contrast, the success of predation by brown trout did not change significantly over the same temperature range (Ward 2011).

3.5.3.2 Warmwater Nonnative Species

Surveys of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead, as well as experimental fish removal studies, indicate the presence of 17 nonnative warmwater fish species (Trammell and Valdez 2003; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011; Albrecht et al. 2014) (Table 3.5-2). Among the species collected, the common carp, fathead minnow, and red shiner are generally the most common warmwater species in the mainstem and tributaries (Rogers and Makinster 2006; Ward and Rogers 2006; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011). Smaller warmwater nonnative species, such as fathead minnow, red shiner, plains killifish, and bullhead, are primarily found in tributaries, especially in the Little Colorado River, but may also be found in the mainstem below the Little Colorado River confluence (Johnstone and Lauretta 2007).

Warmwater nonnative species have been collected in low numbers and only sporadically in the Glen Canyon reach; species collected include the common carp, channel catfish, and fathead minnow (Johnstone and Lauretta 2007; Ackerman 2008). Other species collected from this reach include green sunfish, smallmouth bass, striped bass, redside shiner, golden shiner, and walleye (FWS 2008). During July 2015, a large, reproducing population of green sunfish was discovered in a slough at RM 12, approximately 3 mi downstream of Glen Canyon Dam. Neither the source nor mechanism of introduction for some of these species (e.g., green sunfish, smallmouth bass) into the Glen Canyon reach is known with certainty; however, the nearest source for a number of these species is Lake Powell.

Warmwater nonnative species collected from the mainstem Colorado River in the vicinity of the Little Colorado River confluence include smallmouth and striped bass, green sunfish, black and yellow bullhead, red shiner, and plains killifish (Trammell and Valdez 2003; Johnstone and Lauretta 2007; FWS 2008).

Based on surveys conducted below Diamond Creek (RM 226–276.5) in 2005, the most abundant nonnative fish species included red shiner, mosquitofish, channel catfish, and common carp (Ackerman et al. 2006). Albrecht et al. (2014) reported that native fishes composed approximately 98% of the total age-0 catch during 2014 surveys and dominated the total number of small-bodied fish captured during 2013–2014 surveys in the lower Grand Canyon (Lava Falls to Pearce Ferry); bluehead sucker, flannelmouth sucker, and speckled dace were the most common native species collected. Eight nonnative species were captured during 2013–2014 surveys, including brown trout, rainbow trout, common carp, channel catfish, fathead minnow, plains killifish, western mosquitofish, and red shiner (Albrecht et al. 2014). Bridge Canyon Rapid (RM 235.1) may provide a natural impediment to the upstream movement of many of the nonnative fish except striped bass, walleye, and channel catfish (Valdez and Leibfried 1999; Reclamation 2011a).

The Little Colorado River may represent a source for some nonnative fishes found in the mainstem Colorado River (Stone et al. 2007). As many as 20 species of warmwater nonnative fishes have been reported from the Little Colorado River watershed (Table 3.5-4). Warmwater species collected from the Little Colorado River below Chute Falls include common carp, red shiner, fathead minnow, plains killifish, black bullhead, and channel catfish (Table 3.5-3) (Ward and Persons 2006; FWS 2008). Standardized monitoring from 1987 to 2005 found that nonnative warmwater fish generally compose only a small percentage of the fish collected from the Little Colorado River, typically accounting for less than 10% of the total fish catch in any single year (Ward and Persons 2006). Six species of warmwater nonnative fish (common carp, fathead minnow, red shiner, channel catfish, yellow bullhead, and plains killifish) are known to reproduce in the Little Colorado River (Choudhury et al. 2004).

Climatologists predict that the Southwest will experience extended drought due to global climate change, and lower Lake Powell Reservoir elevations and warmer release temperatures are predicted (Seager et al. 2007; CCSP 2008a,b). Warmer water conditions could benefit warmwater nonnative fishes, result in invasions of new species, and cause greater proliferation of existing nonnative fish species (Rahel and Olden 2008).

3.5.3.3 Interactions with Native Species

Nonnative fish in the Colorado River are considered to adversely affect native fish in the system through predation and/or competition, and by serving as hosts for parasites (Minckley 1991; Coggins et al. 2002, 2011; Gloss and Coggins 2005; Olden and Poff 2005).

Predation and Competition. Piscivory by rainbow and brown trout has been suggested as a large source of mortality for native fish in the Colorado River and its tributaries below Glen Canyon Dam (Blinn et al. 1993; Marsh and Douglas 1997; Yard et al. 2011; Whiting et al. 2014). Near the confluence of the Little Colorado River, Yard et al. (2011) found that 90% of the vertebrate prey consumed by rainbow and brown trout were fish and estimated that rainbow and brown trout consumed over 30,000 fish in the vicinity of the Little Colorado River during a 2-year study period. The incidence of piscivory (proportion of individuals feeding on fish) by species was 70% for brown trout and only up to 3.3% for rainbow trout. However, rainbow trout were approximately 50 times more abundant during the study period, and it was estimated that they accounted for more than half of the total number of fish consumed in the study area (Yard et al. 2011). Overall, trout ate 85% more native fish than nonnative fish, even though native fish composed less than 30% of the small fish available as prey in the study area. Of ingested fish that were identifiable, 56% was composed of native fish, while another 28.8% was composed of unidentified suckers (presumably native flannelmouth and bluehead suckers). Of the identified native fish consumed by the trout, about 27% were humpback chub, 15% were speckled dace, 11% were flannelmouth sucker, and 3% bluehead sucker (Yard et al. 2011). Because the majority of humpback chub consumed by trout during the study were YOY and subadults (<3 years), predation on such fish could affect recruitment to the humpback chub population in the Grand Canyon (Coggins and Walters 2009; Yard et al. 2011). Because of differences in the levels of piscivory exhibited by brown and rainbow trout, current decisions to

TABLE 3.5-4 Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed[a,b]

Species	Below Chute Falls	Above Chute Falls
Black bullhead	X	X
Yellow bullhead	X	X
Common carp	X	X
Channel catfish	X	X
Green sunfish	X	X
Fathead minnow	X	X
Plains killifish	X	X
Red shiner	X	X
Threadfin shad	–	X
Goldfish	–	X
Golden shiner	–	X
Northern pike	–	X
Mosquitofish	–	X
Rock bass	–	X
Bluegill	–	X
Smallmouth bass	–	X
Largemouth bass	–	X
Black crappie	–	X
Yellow perch	–	X
Walleye	–	X

[a] X = present; – = absent.

[b] Fish reported from below and above Chute Falls within the 21-mi perennially flowing portion of the Little Colorado River corridor.

Sources: Ward and Persons (2006); Stone et al. (2007).

implement removal actions at the Little Colorado River to benefit humpback chub are triggered by levels of both brown trout and rainbow trout present in the reach, as well as consideration of the status (estimated size) of the humpback chub population.

In the Grand Canyon, brown trout, rainbow trout, channel catfish, and black bullhead are considered the primary predators of humpback chub, while common carp are a major humpback chub egg predator in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; FWS 2008). Fathead minnow, red shiner, and plains killifish may be important predators and competitors of young humpback chub, especially in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; FWS 2008). Marsh and Douglas (1997) examined predation of native fish by nonnative fish in the Little Colorado River and found rainbow and brown trout, channel catfish, and black and yellow bullhead to be predators of native fish. In stomachs from these species that contained food, native fish composed about 14% of the ingested materials, and ingested species included humpback chub, speckled dace, and bluehead and flannelmouth suckers. Whiting et al. (2014) evaluated diets of rainbow and brown trout from Bright Angel Creek, another tributary of the Colorado River in the Grand Canyon, and found that native fish (primarily speckled dace) composed approximately 4% of the diet for larger rainbow trout and 19% of the diet for larger brown trout.

While trout predation on humpback chub has been demonstrated, it is uncertain whether or not trout piscivory has had (or has) a population-level effect on the humpback chub (Yard et al. 2011). Although survival and recruitment of humpback chub have increased following trout removal in 2003 and 2006, it is not known if this increase is due to trout removal or other environmental factors, and further experimentation would be needed to tease apart other system-level dynamics that could have contributed to adult humpback chub population increases observed since 2000. For example, the temperature of water released from Glen Canyon Dam increased during the trout removal study period to temperatures that may have improved humpback chub growth and survival (Coggins et al. 2011). Ongoing studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout (e.g., Ward 2011; Ward and Morton-Starner 2015; see Section 3.5.3.1).

In addition to predation, nonnative fish may affect native fish through competition for resources that may be limited, such as food or appropriate habitat. Many of the small-bodied fish (including juveniles of larger species) in the Colorado River downstream of Glen Canyon Dam share similar habitats and food items, thereby increasing the potential for resource competition (Seegert et al. 2014). For example, nonnative fathead minnows are likely to compete with juvenile bluehead and flannelmouth suckers for resources, since they occupy the same habitat types and also have a high degree of overlap in the types of food items eaten (Seegert et al.2014. Diet evaluations and stable isotope analyses for fish from Bright Angel Creek found that the diets of rainbow trout and small (<150 mm total length) brown trout overlap with native fishes, suggesting competition for food resources (Whiting et al. 2014). Although the magnitude of species-level effects among the various native and nonnative species is poorly understood in most cases, it is likely that such competition has an effect on the abundance and survival of native species.

Research on the food web dynamics of the Grand Canyon provides further evidence that competition between native fish and nonnative fishes is likely occurring. Invertebrates, primarily blackflies and midges, are important food items for both humpback chub and nonnative fishes, particularly rainbow trout. Throughout Marble and Grand Canyons, invertebrate production is low, and fishes consume most of this production. Cross et al. (2013) hypothesized that an influx of rainbow trout from upstream, coupled with this limited resource base, may lead to strong competition among fishes in the Grand Canyon, and that dam operations that alter fish populations such as HFEs may exacerbate this effect.

Parasites and Diseases. The introduction and establishment of nonnative fish in the Colorado River below Glen Canyon Dam has also resulted in the introduction of several species of fish parasites that have the potential to adversely affect native fishes in the system

(Clarkson et al. 1997; Choudhury et al. 2004). Whirling disease, which affects rainbow trout but not the other native or nonnative species in the Colorado River below Glen Canyon Dam, was discussed above. The Asian tapeworm and the anchor worm have been found in native and nonnative warmwater fish in the Colorado River and its tributaries below Glen Canyon Dam, and the prevalence of these parasites is especially high in the Little Colorado River (Clarkson et al. 1997; Choudhury et al. 2004). For example, since first being identified from humpback chub in the Little Colorado River in 1990, reported infestation rates of the Asian tapeworm in native fish in the Little Colorado River were over 50% in some life stages of the humpback chub and as much as 60% in juvenile speckled dace (Clarkson et al. 1997). A 2-year seasonal study of fish parasites in the Little Colorado River reported 17 species of parasites from 4 native and 7 nonnative fish (Choudhury et al. 2004).

The effects of parasite infestation may be serious. For example, pathological effects of the Asian tapeworm have been reported to include intestinal abrasion and disintegration, as well as blockage and perforation of the gastrointestinal tract; chronic effects may include reduced growth and reproductive capacity, depressed swimming ability, and secondary bacterial infections (Clarkson et al. 1997). Fish larvae infested with the anchor worm may be killed, if vital organs are penetrated by the anchors, and secondary infections are possible at attachment points (Berry et al. 1991).

The effects of many of the parasites that have been reported for other fish species suggest that these parasites have the potential to adversely affect native fishes in the Colorado River below Glen Canyon Dam. The high prevalence of parasites in native and nonnative fish in the Little Colorado River may be especially of concern, given the importance of the Little Colorado River in the reproduction of the humpback chub and maintenance of the humpback chub population in the Colorado River below Glen Canyon Dam.

The potential for expansions and infestations of nonnative parasites may also be influenced by water temperatures. Rahel and Olden (2008) suggested that climate change could facilitate expansion of nonnative parasites. This may be an important threat to humpback chub. Optimal Asian tapeworm development occurs at 25–30°C (77–86°F) (Granath and Esch 1983), and optimal anchorworm temperatures are 23–30°C (73–86°F) (Bulow et al. 1979). Cold water temperatures in the mainstem Colorado River in Marble and Grand Canyons have likely prevented these parasites from completing their life cycles and limited their distribution. Warmer climate trends or operational alternatives could result in warmer overall water temperatures, thereby increasing the prevalence of these parasites, which can weaken humpback chub and increase mortality rates.

3.5.3.4 Nonnative Fish Control Activities and Effects of Flow Conditions

A number of management activities have been designed and implemented to test their efficacy for controlling and reducing the abundance and distribution of nonnative fishes in the Colorado River and its tributaries below Glen Canyon Dam. These control activities included (1) flow releases from Glen Canyon Dam designed to reduce trout recruitment, and (2) mechanical removal of trout and warmwater nonnative fish in the vicinity of the Colorado

River–Little Colorado River confluence (Reclamation 2011e). A series of HFEs was conducted in 1996, 2004, 2008, 2012, 2013, and 2014 to benefit sandbar resources, improve camping beaches, and potentially improve the quality of shoreline habitats for native fish in GCNP (Melis et al. 2010, 2012). Dodrill et al. (2015) reported that although experimental floods increased the prevalence and extent of backwaters, the effects were modest and would be expected to dissipate quickly. There was a large increase in rainbow trout early life stage survival rates and in the abundance of rainbow trout following the 2008 spring HFE; whether such increases would be supported by future spring HFEs is unclear, and the effects of fall HFEs on rainbow trout are less clear; however, preliminary analyses of recent studies indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015). The potential effects of HFEs on trout are described below, as are the possible effects of equalization flows on trout.

Nonnative Fish Suppression Flows

Flows designed to reduce trout recruitment in Lees Ferry were tested in 2003–2005. These flows, conducted from January through March, were intended to dewater and expose rainbow trout redds in the Glen Canyon reach to lethal air temperatures for part of the day, thereby reducing the survival of trout eggs in the exposed redds (Korman et al. 2005; Korman, Kaplinski, et al. 2011; Korman and Melis 2011). The flow regimes tested during this period consisted of increasing the extent of daily flow variation during winter and early spring from the normal range of 10,000–18,000 cfs in January and 7,000–13,000 cfs in February–March to a range of 5,000–20,000 cfs in January–March; these operations also resulted in longer periods of dewatering for redds at lower elevations than would occur under normal operations. The fluctuating flows were determined to have resulted in increasing the incubation mortality rate from 5–11% under normal flow conditions to 23–49% under fluctuating flows (Korman et al. 2005; Korman, Kaplinski, et al. 2011; Korman and Melis 2011). However, no measurable reduction in age-0 abundance was observed, presumably due to increased survival of those rainbow trout that survived. These results suggest that the increased level of incubation mortality did not exceed compensatory survival responses (Korman, Kaplinski, et al. 2011). Because of these results, it has been suggested (Korman, Kaplinski, et al. 2011; Korman and Melis 2011) that a more limited fluctuating flow regime may be effective, targeting juvenile trout after the majority of density-dependent responses to egg incubation and hatching success have been realized, but before age-0 trout leave habitats that are potentially more sensitive to flow fluctuations. Testing flow regimes under which flow variation is increased during late spring and summer months when small age-0 trout are utilizing potentially flow-sensitive, low-angle habitat has been suggested (Korman et al. 2005; Korman and Melis 2011).

Nonnative Fish Removal

The removal of predatory nonnative fish has been conducted in various locations in the upper and lower basins of the Colorado River since the mid-1990s with varying degrees of success (Mueller 2005). Removal of nonnative fish in the Colorado River near the Little Colorado River confluence was conducted from 2003 to 2006, and in 2009 (Korman et al. 2005;

Makinster et al. 2009; Coggins et al. 2011). Fish removal activities in 2003–2006 captured more than 36,000 fish, of which 23,266 were nonnative species (including 19,020 rainbow trout) (Korman et al. 2005; Coggins et al. 2011). The removal of trout was estimated to have reduced rainbow trout abundance in this reach from about 6,500 in January 2003 to about 620 in February 2006. Immigration and recruitment account for the difference between the number of trout removed and the abundance estimates. During the 2003–2006 removal activities, large increases in the abundance of fathead minnow and black bullhead were reported beginning in September 2005, suggesting increases in immigration, survival, or both. The observed increase may have been due to increased emigration from the Little Colorado River where these species spawn, or because the combination of reduced rainbow trout numbers and increasing water temperatures may have caused these species to be more abundant and susceptible to capture (Coggins et al. 2011).

Coincident with the 2003–2006 removal activities, the humpback chub population stabilized and increased, suggesting that the nonnative fish removal (especially the removal of rainbow trout) may have allowed higher survival and recruitment by humpback chub (Coggins and Walters 2009; Coggins et al. 2011). However, the relationship between trout removal and survival of humpback chub is not clear because there was a system-wide decrease in rainbow trout abundance and drought-induced increases in river water temperatures during the time of the removal activities that could also have led to increased survival and recruitment of juvenile native fish (Coggins et al. 2011). As indicated in Figure 3.5-3, stabilization and increases in the adult humpback chub population may have begun as early as 2002, prior to the nonnative fish removal actions. Because changes in the adult humpback chub population rely, in part, on survival and recruitment of juvenile humpback chub, increases in survival rates may have occurred for several years prior to the fish removal activities. Further, even though the abundance of trout appeared to return to pre-removal levels by 2009, the estimated adult abundance of humpback chub continued to increase (Figure 3.5-3)

Nonnative fish removal was also conducted in 2009, the results of which indicated that rainbow trout abundance in the vicinity of the Little Colorado River had rebounded from the declines observed in 2006–2007 (Coggins et al. 2011; Reclamation 2011a). The number of rainbow trout in the vicinity of the Little Colorado River prior to the 2009 removal activities was estimated to be similar to the high densities estimated in 2002 (prior to the 2003 fish removal activities) (Wright and Kennedy 2011).

Nonnative fish removal is also being conducted in Shinumo and Bright Angel Creeks to restore and enhance the native fish communities and to reduce predation and competition on endangered humpback chub from nonnative fish. These removals are being conducted to implement conservation measures identified in the 2008 Biological Opinion, the 2009 Supplement, and the 2011 Biological Opinion on the operation of Glen Canyon Dam (FWS 2008, 2009; Reclamation 2011a). Nonnative fish (primarily rainbow trout) are being removed from Shinumo Creek to minimize predation upon newly translocated humpback chub and to reduce competition. From 2009 through 2014, 5,569 rainbow trout were removed from Shinumo Creek using netting, angling, and electrofishing. Brown trout do not occur in Shinumo Creek above a waterfall barrier near the mouth, but a few brown trout were removed below the waterfall. Rainbow trout densities were reduced between summer 2011 and winter 2012, but rebounded with a strong cohort in June 2012 (likely a "compensatory response"). Abundance of bluehead sucker increased in the lower reaches downstream of translocation areas and speckled dace increased throughout Shinumo Creek as rainbow trout densities were reduced. A sequence of headwater fires and floods occurred in the summer of 2014 that almost eliminated all nonnative and native fish from Shinumo Creek. NPS plans to remove the remaining nonnative trout and monitor the native fish. Nonnative fish, primarily rainbow trout, occur in small numbers in Havasu Creek and are also removed when encountered (Healy et al. 2014).

From 2010 to 2012, trout reduction efforts in Bright Angel Creek included the installation and operation of a fish weir trap and backpack electrofishing in the lower portion of the creek, including the confluence of Bright Angel Creek to Phantom Creek. From 2012 to 2015, removals were expanded to encompass the entire length of Bright Angel Creek (approximately 16 km) and Roaring Springs (approximately 3 km). The operation of the weir was also extended from October through February to capture greater temporal variability in the trout spawning migration. From 2010 to December 2014, about 28,000 brown trout and 4,800 rainbow trout were removed from Bright Angel Creek from both the weir and by electrofishing. Data on early 2015 removals and native fish response are still being analyzed, but trout abundance appears to have been reduced and native fish distribution has expanded upstream. These data are preliminary and may change slightly with further analysis (Healy et al. 2014; Nelson et al. 2012, 2015). As determined through consultation with Traditionally Associated Tribes and others, and consistent with the Memorandum of Agreement between the NPS and the Arizona State Historic Preservation Office, trout removed from the creeks were preserved and distributed for beneficial use through human consumption, or for use by the Tribes for other purposes.

In July of 2015, AZGFD biologists discovered an unusually large, reproducing population of green sunfish in a backwater slough connected to the mainstem Colorado River approximately 3 mi downstream of Glen Canyon Dam. Although the downstream end of the slough is connected to the main channel under the typical range of releases from Glen Canyon Dam, the upstream end of the slough is isolated from the main channel except during high flows. Green sunfish are known to be prolific, with a single female capable of producing up to 10,000 eggs. Green sunfish are considered likely predators of small-bodied native fish and native fish eggs. Biologists with the AZGFD, NPS, USGS, FWS, and Reclamation have determined that green sunfish pose a threat to native fish, including the humpback chub. Two removal efforts using electrofishing, seine netting, and trapping were conducted in August of 2015, but failed to deplete the population despite removing more than 3,000 fish. Biologists from the NPS and AZGFD constructed and installed a large block net at the downstream end of the main slough to minimize the escapement of green sunfish. After analyzing alternative methods for control, the agencies authorized a short-term targeted treatment of the slough with the fish toxin rotenone. Information available as of mid-November 2015 indicates that the eradication efforts appear to have been successful at controlling this population.

In August of 2016, NPS biologists discovered an additional small number of green sunfish in the slough. At the time of preparation of this EIS, mechanical removal efforts with beneficial use were being conducted.

Tribal Perspectives on Nonnative Fish Removal

Both the Hopi Tribe and the Pueblo of Zuni have expressed concerns to the U.S. Department of the Interior (DOI) regarding management actions described above involving fish suppression flows and mechanical removal of nonnative fish. The Hopi have expressed concern regarding the mechanical removal of large numbers of trout and trout management flows, while also expressing an understanding of the need to effectively manage nonnative populations if necessary to prevent the extinction of humpback chub. The Hopi stated their concern of conflicting management objectives to maintain a trout fishery while also minimizing threats to humpback chub. The Pueblo of Zuni consider these actions to be the taking of life without a beneficial use.

During the important Zuni migrations in Grand Canyon many culturally and historically important events occurred. One such specific event occurred in Zuni history which defines the Zuni's familial relationship to aquatic life and provides the fundamental basis for the Zuni objection to the mechanical removal of fish from the confluence of the Colorado and the Little Colorado rivers. In the late nineteenth century, Frank Hamilton Cushing recorded this historical event as it was narrated to him by the Zuni. Cushing labeled the event as the "Abode of the Souls" and the following is a condensed version of that event:

Shortly after Emergence, men of the Bear, Crane, and Seed clans strode into the red waters of the Colorado River and waded across. The men of the clans all crossed successfully. The women travelling with the men carried their children on their backs and they waded into the water. Their children, who were unfinished and immature (because this occurred shortly after Emergence), changed in their terror. Their skins turned cold and scaly and they grew tails. Their hands and feet became webbed and clawed for swimming. The children fell into the swift, red waters. Some of the children became lizards, others turned into frogs, turtles, newts and fish. The children of these clans were lost to the water. The mothers were able to make it to the other side of the river, where they wailed and cried for their children. The Twins heard them, returned, and advised the mothers to cherish their children through all dangers. After listening to the Twins, those people who had yet to pass through the river took heart and clutched their children to them and safely proceeded to the opposite shore. The people who successfully made it out of the river rested, calmed the remaining children, and then arose and continued their journey to the plain east of the two mountains with great water between. Thence, they turned northward to camp on the sunrise slopes of the uppermost mountains.

High-Flow Experiments

A number of HFEs have been conducted in the Colorado River below Glen Canyon Dam (1996, 2004, 2008, 2012, 2013, and 2014) to improve camping beaches and potentially improve the quality of shoreline habitats for native fish in GCNP (Melis et al. 2010, 2012). Rainbow trout abundance was found to increase following the spring HFEs in 1996 and 2008 (Makinster et al. 2011; Kennedy and Ralston 2011). In particular, the 2008 cohort was the largest on record up to that date, while the 2009 cohort was very strong compared to other years (Korman, Kaplinski, et al. 2011; Korman and Melis 2011). While fish hatched before and up to

1 month after the HFE showed lower early survival rates, fish hatched more than 1 month after the HFE showed a large increase in their early survival rate, with age-0 fish abundance being four times higher than expected (Melis et al. 2010; Korman and Melis 2011).

It is thought that cohorts produced after the HFE were not exposed to high flows and emerged into better quality habitat with better food availability (Rosi-Marshall et al. 2010). Concentrations of invertebrate prey in the drift following the spring 2008 HFE showed some prey items such as midge and blackflies (primary preferred food of rainbow trout) to have increased as much as 400% to 800%, and elevated levels in the drift continued for as much as 15 months following the HFE (Melis 2011). The observed changes in rainbow trout abundance following these two HFEs suggest that spring HFEs may benefit rainbow trout populations (Kennedy and Ralston 2011).

In contrast to the increased abundance of rainbow trout following the spring HFEs in 1996 and 2008, trout abundance was reduced following the fall (November) HFE in 2004 (Kennedy and Ralston 2011). However, rainbow trout in the Glen Canyon reach were showing a general population decline that started 2 years prior to the 2004 HFE, and, therefore, results in uncertainty regarding the inferences about the influence of the fall 2004 HFE on rainbow trout abundance and whether the response to fall HFEs is different from those associated with spring HFEs. Preliminary analyses indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012 and 2013 (VanderKooi 2015; Gimbel 2015). In addition, the relative overall abundance of rainbow trout in the Glen Canyon reach declined from 2012 to 2013 (Figure 3.5-6) due to declines in abundance of fish in smaller size classes.

Equalization Flows

There is also a potential for the abundance of YOY rainbow trout to be affected by the high, steady, and sustained flows that result from equalization flows as required by the 1968 Colorado River Basin Project Act. A substantial increase in numbers of age-0 trout was observed in 2011 following a period of sustained high flows required for equalization (Korman, Persons, et al. 2011). It has been hypothesized that the high, steady flows associated with equalization operations could benefit age-0 rainbow trout by inundating additional habitat for spawning, incubation of eggs, and production of food resources, and that these factors resulted in the observed increase in the numbers of age-0 trout.. Implementation of equalization flows is separate and distinct from LTEMP and would not be affected by LTEMP.

3.6 VEGETATION

Terrestrial plant communities along the Colorado River from Glen Canyon Dam to Lake Mead are highly diverse due to great variations in landforms, geologic features, and physical characteristics such as topography, elevation, and aspect. Plant communities along the Colorado River are greatly influenced by flow characteristics.

3.6.1 Historic and Remnant Riparian Plant Communities

A natural riverine environment existed along the Colorado River corridor prior to the modifications in flow regime and sediment transport that resulted from the construction of Glen Canyon Dam (Turner and Karpiscak 1980). Conditions within riparian habitats were constantly changing and highly unstable, with wide variations in annual flood flows as well as annual periods of low flow (Clover and Jotter 1944; Turner and Karpiscak 1980). Seasonal floods, averaging about 86,000 cfs, but frequently exceeding 100,000 cfs (Johnson 1991), resulted from snowmelt and spring rains; while sporadic floods from tributaries resulted from local storms, particularly during the summer monsoon season. Flood flows provided soil moisture which created opportunities for the establishment of species adapted to wet or moist soils near the river across a highly variable range of stage elevation (Clover and Jotter 1944). Floods were also sources of disturbance, removing plants by drowning or scouring across that elevation range (Clover and Jotter 1944). While well-established willows in some locations of the lower Grand Canyon could reach a height of 30 to 40 ft, these willows could be partially or completely removed by floods (Clover and Jotter 1944). Vegetation was typically sparse in areas that were frequently flooded; however, when a number of years passed between flood events, denser growth could develop. In broader reaches of the canyon, scouring was somewhat diminished, allowing some perennial plants to become established in sediment deposits near the river (Turner and Karpiscak 1980).

A zone of riparian vegetation, referred to as the Old High Water Zone, was well established just above the pre-dam scour zone (at and just above the approximately 100,000-cfs stage elevation) (Carothers and Brown 1991). Following dam construction, annual high flows have been limited to approximately 45,000 cfs or lower, except for four higher flow years (1983–1986) since 1965. These relatively low annual high flows have permitted riparian vegetation to develop below the Old High Water Zone in what has become known as the New High Water Zone. Before the dam, annual high flows carried large sediment loads through Glen and Grand Canyons, scouring nearly all vegetation below the Old High Water Zone (Carothers and Brown 1991; Kearsley and Ayers 1999; Ralston 2005).

The principal species[8] of the Old High Water Zone in Glen Canyon included New Mexico olive (*Forestiera pubescens*), Apache plume (*Fallugia paradoxa*), and netleaf hackberry (*Celtis reticulata*), and in Glen and upper Marble Canyons included apache plume, netleaf hackberry, western redbud (*Cercis occidentalis*), live oak (*Quercus turbinella*), and New Mexico olive. The Grand Canyon lacks the latter two species in the river corridor, and catclaw acacia (*Acacia greggii*) and mesquite (*Prosopis glandulosa*) are dominant, with desert broom (*Baccharis sarothroides*) becoming important downstream from RM 127 (Spence 2006; Carothers and Brown 1991; NPS 2005a). Pre-dam sediment terraces occupy the upper levels of the Old High Water Zone and support species adapted to dry soil conditions. High terraces in Glen Canyon support dense stands of four-wing saltbush (*Atriplex canescens*); however, in the Grand Canyon, catclaw acacia, brittlebush (*Encelia* spp.), barrel cactus

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[8] Plant names in this section use the Flora of North America (FNA 2014) and TROPICOS (Tropicos 2014) nomenclatures.

(*Ferocactus cylindraceus*), bursage (*Ambrosia dumosa*), creosote (*Larrea divaricata*), ocotillo (*Fouquieria splendens*), and other Mojave-Sonoran desert species also occur (Spence 2006).

Surfaces that were subject to frequent floods prior to dam construction ranged from barren to sparsely vegetated (Turner and Karpiscak 1980). Some of the species that occurred prior to the dam in this sparsely vegetated zone included tamarisk, also known as salt cedar (*Tamarix* spp.); seepwillow (*Baccharis* spp.); arrowweed (*Pluchea sericea*); and coyote willow (*Salix exigua*). Tamarisk, a species of Eurasian origin, was described in the 1930s as occurring along the river in “thickets near the eastern end of the park,” “fringing the river near the mouth of Bright Angel Creek” (Dodge 1936), and “along the river from Nankoweap Creek to the base of Tanner Trail” (GCNHA 1936). Historic photos from Lees Ferry show tamarisk had established by 1923 (Graf 1978). Clover and Jotter (1944) noted tamarisk occurred in scattered locations (in moist sand near the river’s edge) along the length of the river except for a large section of Marble Canyon; it was observed at and above Lees Ferry, below Vasey’s Paradise, at the mouth of Saddle Canyon, Lava Pinnacle, and at Separation Rapids. Based on analyses of pre-dam photographs, tamarisk probably occurred as widespread isolated individuals (Turner and Karpiscak 1980).

3.6.2 Existing Riparian Vegetation Downstream from Glen Canyon Dam

The response of riparian vegetation to the operation of Glen Canyon Dam has been well studied, as summarized by Ralston (2012) and Sankey, Ralston, et al. (2015). Most evidence indicates that riparian vegetation composition, structure, distribution, and function are closely tied to ongoing dam operations. “Riparian vegetation” includes all plants found within the Fluctuating, New High Water, Old High Water, and Pre-Dam Flood Terrace hydrologic zones of the mainstem Colorado River downstream from Glen Canyon Dam, as described below.

Following construction of Glen Canyon Dam and the regulation of flows, including the reduction in annual flood peaks and increased year-round water availability at lower stage elevations, riparian vegetation expanded into the newly stable habitat and increased substantially (Ralston 2010; Kennedy and Ralston 2011; Webb et al. 2011; Sankey, Ralston, et al. 2015; Turner and Karpiscak 1980). The overall trend since completion of the dam has been the encroachment of New High Water Zone vegetation onto sandy beaches (Kearsley et al. 1994; Webb et al. 2002). At the same time, water availability decreased or was eliminated at higher elevations above the average annual daily maximum flows. The overall trend in the Old High Water Zone has been increased mortality of species such as mesquite and hackberry (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Plant communities present along the river have developed through associations of species with similar responses to moisture gradients, tolerance to water stress, and modes of reproduction (Kearsley et al. 2006; Stevens et al. 1995; Ralston et al. 2014; Ralston 2012). Such species associations occur on geomorphic surfaces of debris fan-eddy complexes, such as reattachment bars and separation bars, as well as on channel margins between these complexes, and respond dynamically to changes in flow characteristics. Geomorphic setting, substrate type/texture, hydrology, and species life history characteristics affect the temporal and spatial occurrence of plant communities (Ralston et al. 2014; Merritt et al. 2010). Because of historical patterns of dam releases, communities below the 25,000-cfs elevation on these surfaces differ somewhat from those above that level. Seven plant community types have been identified as occurring on these geomorphic surfaces (Ralston et al. 2014) and are given in Table 3.6-1.

Vegetation zones along the river reflect the frequency of inundation and disturbance (Ralston 2010, 2012; Kennedy and Ralston 2011). The Fluctuating Zone (Figure 3.6-1) supports flood-tolerant marsh species such as sedges, rushes, cattail, horsetail, and common reed. These species occupy return current channels and successional backwaters that are inundated daily for at least part of the year (i.e., up to the elevation of the average annual daily maximum discharge of about 20,000 cfs). The New High Water Zone lies within the influence of dam operations but above daily fluctuation levels (Carothers and Brown 1991). Vegetation in the Fluctuating and New High Water Zones are greatly influenced by river flow and dam operations but above daily fluctuation levels (Carothers and Brown 1991). Vegetation in the Fluctuating and New High Water Zones are greatly influenced by river flow and dam operations. (Stevens et al. 1995; Porter 2002; Kearsley and Ayers 1999; Kearsley et al. 2006; Ralston 2005, 2012).

The New High Water Zone, inundated by flows up to 45,000 cfs, supports woody riparian species, many herbaceous obligate riparian species (e.g., *Carex* spp., *Juncus* spp., *Equisetum* spp., *Phragmites australis*, and *Typha* spp.) with bunchgrasses such as sand dropseed and shrubs such as spiny aster at upper elevations. The dominant woody species of the Glen Canyon and Grand Canyon New High Water Zone scrub communities include tamarisk, coyote willow, arrowweed, and seepwillow (*Baccharis* spp.), along with desert broom downstream from RM 162 (Spence 2006). Wide, alluvial reaches have greater vegetation cover than narrow, confined reaches (Kennedy and Ralston 2011).

The Old High Water Zone, above 60,000 cfs to approximately 200,000 cfs, supports pre-dam drought-tolerant riparian species found in riparian and upland habitats, such as honey mesquite, catclaw acacia, netleaf hackberry, Apache plume, New Mexico olive, and mountain pepperweed (*Lepidium montanum*), along with desert species such as Mormon tea (*Ephedra* spp.), prickly pear (*Opuntia* spp.), creosote, ocotillo, and brittlebush. Mortality of Old High Water Zone plants is occurring, and some species such as mesquite and hackberry are no longer recruiting in this zone because of the lack of sufficiently high flows and nutrient-rich sediment inputs; however, mesquite and catclaw acacia are now recruiting in the New High Water Zone (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011; Ralston 2005). Because flows do not exceed 45,000 cfs with normal dam operations, the upper margins of this zone are moving downslope, resulting in a narrowing of the zone. Desert species occupy pre-dam flood terraces and windblown sand deposits above the Old High Water Zone.

Vegetation on the geomorphic surfaces along the river (below about the 45,000-cfs stage elevation) has changed since construction of the dam as a function of river flows and climate (precipitation), as well as a result of factors such as increased soil salinity and increased sand coarseness (Carothers and Aitchison 1976; Kearsley et al. 2006; Sankey, Ralston, et al. 2015). Return channel-eddy complexes support many of the largest and better developed riparian patches (Spence 2006). Fluvial marsh wetlands were scarce prior to the construction of the dam and were associated only with perennial tributaries and springs (Webb et al. 2002); however,

TABLE 3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and Channel Margins

Plant Community	Dominant Species	Geomorphic Surfaces
Common reed temperate herbaceous vegetation	Common reed (*Phragmites australis*), cattail (*T. latifolia, T. domingensis*), common tule (*Schoenoplectus acutus*), creeping bent grass (*Polypogon viridis*)	Lower reattachment bar
Coyote willow-Emory seep willow shrubland/horsetail herbaceous vegetation	Coyote willow, Emory seepwillow (*Baccharis emoryi*), horsetail (*Equisetum laevigatum*), common three-square (*Schoenoplectus pungens*), common spike-rush (*Eleocharis palustris*), alkali muhly (*Muhlenbergia asperifolia*)	Lower channel margin, lower reattachment bar
Tamarisk temporarily flooded shrubland	Tamarisk; in Glen Canyon also desert broom	All surfaces
Cottonwood/coyote willow forest	Coyote willow, cottonwood (*Populus fremontii*), Goodding’s willow (*Salix gooddingii*), seepwillow (*Baccharis salicifolia*), salt grass (*Distichlis spicata*), alkali muhly, common reed, horsetail (*Equisetum* spp.), rush (*Juncus* spp.), sedge (*Carex* spp.), Russian olive (*Elaeagnus angustifolia*), tamarisk, creepingbent grass (*Agrostis stolonifera*), sweet clover (*Melilotus* spp.)	Lower separation bar, lower channel margin
Arrowweed seasonally flooded shrubland	Arrowweed (*Pluchea sericea*) in pure stands, or with seepwillow (*Baccharis* spp.), mesquite, or coyote willow	Lower reattachment bar, upper separation bar, upper channel margin, upper reattachment bar
Mesquite shrubland	Mesquite (*Prosopis glandulosa* var. *torreyana*), with seepwillow (*Baccharis* spp.), arrowweed	Lower channel margin, upper separation bar, upper channel margin, upper reattachment bar
Bare sand	Less than 1% vegetation cover	All surfaces

Source: Ralston et al. (2014).

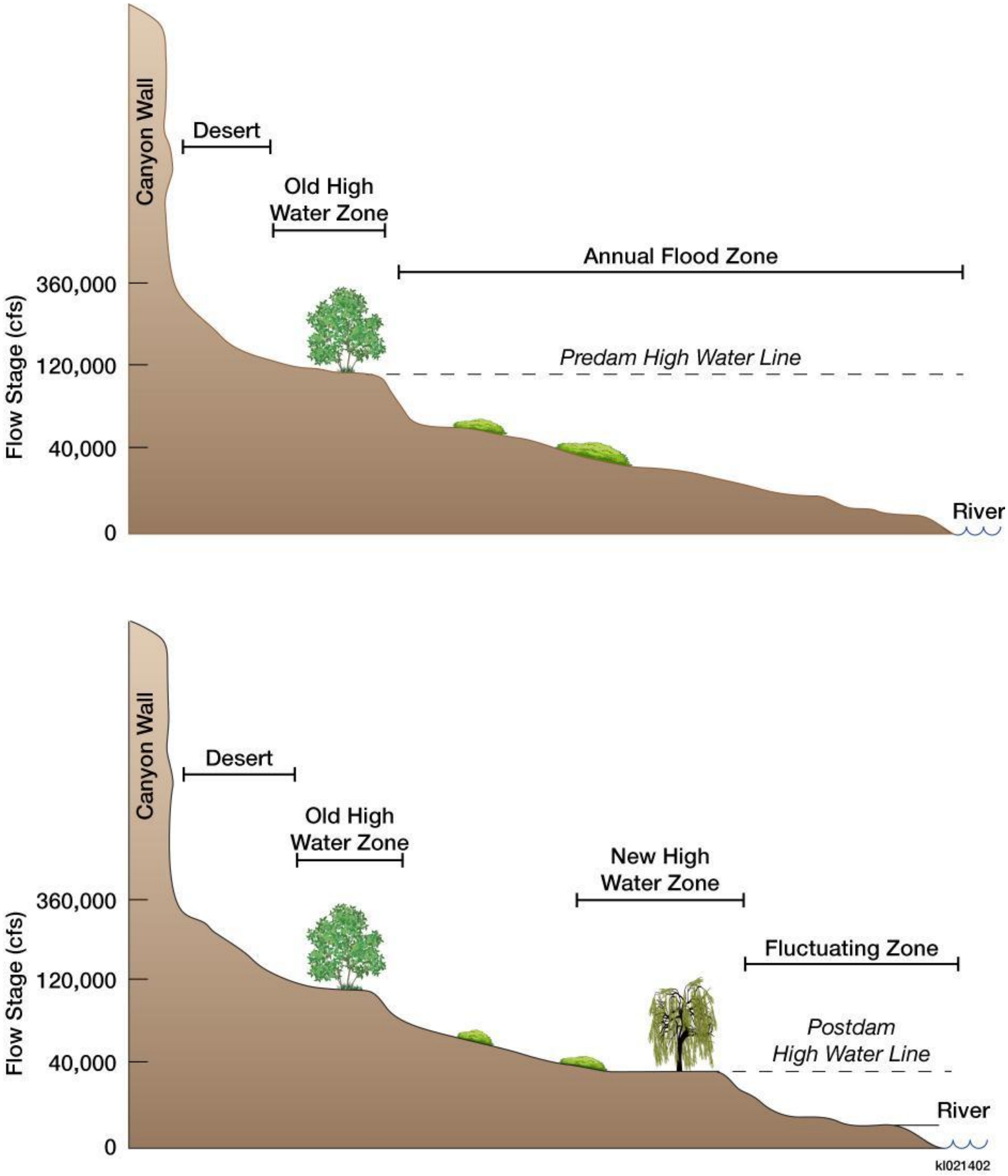

FIGURE 3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam (adapted from Reclamation 1995)

widespread marsh development occurred following the reductions of spring floods, with the number increasing downstream (Stevens et al. 1995). Of the 1,625 ac of riparian vegetation mapped in the New High Water Zone, approximately 5 ac represent marshes, or about 0.3% (because of the typically small size of fluvial marshes, they are underrepresented in the current map, which has a minimum mapping unit of 0.5 ha). Areas mapped as wetland vegetation, including cattails and common reed, in 2002 totaled roughly 10 ac (Ralston 2012; Kennedy and Ralston 2012). Marsh communities are generally dominated by a few species, varying by soil texture and drainage. Wet marsh communities occur on fine-grained silty loams on lower areas of eddy complex sandbars that are frequently inundated and are dominated by cattail and common reed. Loamy sands support an association of horseweed (*Conyza canadensis*), knotweed (*Polygonum aviculare*), and Bermuda grass (*Cynodon dactylon*) (Carothers and Aitchison 1976; Kearsley et al. 2006). Shrub wetland communities (with coyote willow, Emory seep willow, and horsetail the dominant species) occur on sandy soils of reattachment bars and channel margins, below the 25,000-cfs stage, that are less frequently inundated. Clonal wetland species such as cattail, common reed, and willow are adapted to burial and regrowth and recover after burial following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). On areas of higher stage elevations, short-lived plant species such as longleaf brickellbush, brownplume wirelettuce (*Stephanomeria pauciflora*), broom snakeweed (*Gutierrezia microcephala*), brittlebush, and Emory seepwillow colonize recently disturbed surfaces (Bowers et al. 1997; Webb and Melis 1996). While longer-lived species, such as Mormon tea, cactus (*Opuntia* spp.), and catclaw acacia (*Acacia greggii*), are not as quick to colonize disturbed areas, they are expected to continue to expand into lower stage elevations in the absence of disturbance. These species are found on surfaces that have not been disturbed for 7 to 28 years.

The population of Goodding's willow along the river below Glen Canyon Dam appears to have been affected by the reduction in flood flows on upper riparian terraces, has been in decline, and either no longer occurs at or does not reproduce at two-thirds of the sites where it previously existed (GCWC 2011; Mortenson et al. 2008). Along with the coarsening of substrates, the lack of springtime recruitment floods threatens remaining stands; however, high flows during the mid-1980s resulted in some establishment of Goodding's willow in the Grand Canyon (Mortenson et al. 2012; Ralston 2012). Restoration of Goodding's willow and several other native species has been a focus of NPS revegetation efforts.

Beavers (*Castor canadensis*) have reduced Goodding's willow within the canyon and may influence the invasion of resultant open areas (as well as areas of coyote willow herbivory) by tamarisk (Mortenson et al. 2008). Beavers may be more common along the river now due to the increase in post-dam availability of woody plants (Turner and Karpiscak 1980). In addition, Fremont cottonwood (*Populus fremontii*) recruitment along the river is nearly eliminated each year by beaver foraging on cottonwood seedlings, and very few Fremont cottonwood occur along the river below the dam (GCWC 2011).

Arrowweed, a dominant native woody species of both the Old and New High Water Zones, is adapted to burial by sediments deposited by floods (Ralston 2012). This drought-tolerant clonal species responds to burial by resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth (Ralston 2012). Arrowweed has characteristics of a primary colonizer and quickly occupies open sandbar areas. It spreads laterally by underground rhizomes and is commonly found in dense monotypic stands with few individuals of other species intermixed (Ralston et al. 2014), thereby reducing species diversity in areas occupied. Because arrowweed interferes with meeting a management objective of open sand beaches in some areas, the NPS has removed it from targeted campsites.

A number of nonnative plant species, many of which are invasive species, occur throughout the riparian zone; among the most common species are tamarisk, camelthorn (*Alhagi maurorum*), Russian thistle (*Salsola tragus*), ripgut brome (*Bromus diandrus*), red or foxtail brome (*Bromus rubens*), cheatgrass (*Bromus tectorum*), yellow sweetclover (*Melilotus officinalis*), spiny sow thistle (*Sonchus asper*), Ravenna grass (*Saccharum ravennae*), perennial peppergrass (*Lepidium latifolium*), and Bermuda grass (Reclamation 2011d; NPS 2005a). Ralston concludes that operations since the 1996 ROD; Reclamation 1996) have facilitated the recruitment, establishment, and expansion of both native and exotic plant species (e.g., tamarisk) throughout the river corridor. Furthermore, a recent analysis of vegetation data collected by NPS staff from 2007 to 2010 demonstrated an overall increase in exotic plant cover, particularly in the New High Water Zone (Zachmann et al. 2013).

Tamarisk, a shrub or small tree usually less than 20 ft in height, has long been the most prominent of these invasive species. As noted above, tamarisk was present along the river long before construction of Glen Canyon Dam. Tamarisk along the Colorado River is a hybrid of at least two distinct species (including *T. ramosissima* and *T. chinensis*) (Ralston 2010). It has an advantage over native species that require access to groundwater, such as cottonwood and willow, in areas where salinities are elevated or where water tables are lowered (Reclamation 2011b). Tamarisk plants accumulate salt on their leaf surfaces, which then accumulates in the surface layer of soil from dropped leaves (Ladenburger et al. 2006). The germination and establishment of native species can be adversely affected as surface soils increase in salinity, which can occur particularly in the absence of annual flooding and scouring, such as along regulated rivers.

High annual floods during the mid-1980s resulted in high tamarisk mortality, with surviving tamarisk located on upper riparian zone terraces; however, those floods also resulted in high levels of tamarisk establishment on elevations well above current river levels (Mortenson et al. 2012). Tamarisk establishment can increase when flood flows coincide with seed releases during spring and early summer (peaking in late May and early June); floods outside of that period result in little tamarisk recruitment (Mortenson et al. 2012; Stevens and Siemion 2012). Seedling survival is greatest when establishment is above the elevation of subsequent floods (Mortenson et al. 2012).

The tamarisk leaf beetle (*Diorhabda* spp.) has had a marked impact on the ecology of riparian zones in the Grand, Marble, and Glen Canyons in recent years. The beetle was discovered in 2009 near Navajo Bridge and at RM 12 and several locations, including Lees Ferry, in 2010; by 2011, it had become established along the Colorado River, occurring discontinuously from Glen Canyon Dam to RM 213, but primarily upstream of RM 27 and from RM 127 to RM 180, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Permanent monitoring plots established in 2010 near Lees Ferry show evidence of mortality in smaller individuals, plus defoliation rates of 75 to 100%. By late 2012, the tamarisk leaf beetle was widely distributed in the Grand Canyon; as of 2015, there were reports of the beetle downstream past Diamond Creek. The splendid tamarisk weevil (*Coniatus* spp.) also occurs in the Grand Canyon), but much less is known about its abundance, distribution, and impacts. The beetle causes early and repeated defoliation of tamarisk during the summer months (Snyder et al. 2010; Hultine et al. 2010), which may eventually result in mortality after several successive years of defoliation. The long-term effects of the tamarisk leaf beetle and splendid tamarisk weevil on tamarisk abundance and distribution in Glen and Grand Canyons are currently not known; however, plant communities in which tamarisk is currently a dominant species will likely undergo compositional change (Shafroth et al. 2005). The extent of mortality within a tamarisk stand varies by site and may not be extensive; tamarisk may persist despite annual defoliation and may fluctuate with beetle populations (Nagler et al. 2012; Nagler and Glenn 2013). Both native and nonnative plant species may become established on sites of tamarisk mortality, although native species establishment may be slow, and future community composition and habitat characteristics would depend on a variety of site-specific factors, including site hydrology and microclimate, changes in nutrient dynamics, available seed sources, and active restoration efforts (Belote et al. 2010; Hultine et al. 2010; Shafroth, Merritt et al. 2010; Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012; Bateman et al. 2013).

Past flow regimes and past flow experiments provide evidence for the types and scale of potential impacts on vegetation from dam operations. The dynamics of large daily fluctuations on vegetation are known from dam operations prior to 1991. Large daily fluctuations increase the wetted area and thus the sandbar area available for colonization by wetland species; however, erosion exacerbated by fluctuations may limit the available bar area (Stevens et al. 1995). Increases in mean daily flow and daily inundation may remove low stage elevation vegetation and coarsen soil texture. Daily fluctuations also flatten vegetation within the range of fluctuating flows, export leaf litter, and coat leaf surfaces with silt (Stevens et al. 1995).

As a result of interim flows and MLFF, riparian vegetation moved into newly exposed areas and a shift to more upland species in most New High Water Zone vegetation patches was observed in Marble Canyon and Grand Canyon (Kearsley and Ayers 1996). The reduction of daily inundation frequency may increase colonization of wet marsh species at low stage elevations and promote the transition of higher elevation cattail/reed marshes to tamarisk/arrowweed vegetation (Stevens et al. 1995).

As noted above, riparian vegetation communities can be affected by dam operations through scouring and erosion during high flows, drowning, burial by new sediments, and reductions in soil moisture levels; consistent availability of water at low elevations (e.g., below 25,000 cfs) from elevated base flows can promote vegetation growth. Responses of riparian vegetation are affected by the timing, frequency, duration, and magnitude of the river’s hydrology, as well as the variability between years and sequencing of flows (Ralston et al. 2014; Merritt et al. 2010). Additional factors related to flow that influence riparian vegetation include characteristics of deposited sediments (such as water-holding capacity, aeration, and nutrient levels), depth to groundwater, and anoxia in the root zone (Merritt et al. 2010). Flood flows during the mid-1980s resulted in a reduction of more than 50% in woody riparian vegetated area below the 60,000-cfs stage elevation due to scouring and drowning, with shallow-rooted species, such as coyote willow, Emory seepwillow, and longleaf brickellia, experiencing the highest mortality (Ralston 2012). The export of sediments (particularly silts and clays and organic matter) coarsened substrates, affected nutrient concentrations, and reduced opportunities for subsequent recruitment of tamarisk and native shrubs, such as coyote willow and Emory seepwillow (Ralston 2012).

HFEs up to 45,000 cfs rework and rebuild riparian vegetation substrates on sandbars, rocky slopes, debris fans, and return-current channels (Kennedy and Ralston 2011). HFEs also make alluvial groundwater more available to plants growing near and above the 45,000-cfs stage elevation (see Section 4.6.2.1). Seed germination is generally maximized with damp-soil or shallow-water conditions. Floods enhance species diversity, reset successional stages, and prevent monocultures in marsh and wetland habitats, and periodic flooding and drying in wetlands is beneficial to diversity and productivity (Reclamation 2011d; Stevens et al. 1995). Following the first HFE in 1996, total vegetative cover on sandbars was reduced approximately 20%, but there was no significant change in wetland or woodland/shrubland area 6 months later (Kearsley and Ayers 1999). Vegetation may return quickly to sandbars following HFEs; herbaceous plant cover doubled within 6 months after the 2008 HFE, and clonal wetland plants such as common reed quickly established on sandbars and shorelines after the 1996 and 2008 HFEs (Kennedy and Ralston 2011). Over the period of HFEs (since 1996), the long-term trend for vegetation on low stage-elevation sandbars has been one of rapid expansion in spite of the HFEs (Sankey, Ralston et al. 2015).

HFEs may result in minor short-term scouring of plants in the river channel and return current channel marsh communities followed by a rapid recovery, generally in around 6 months (Reclamation 2011b). HFEs, however, do not remove higher elevation vegetation (above 20,000 cfs; Ralston 2010). A September 2000 habitat maintenance flow of 31,000 cfs removed 57% of tamarisk seedlings, while native flood-adapted species increased, potentially by vegetative reproduction (Porter 2002; Ralston 2011). Although some near-shore wetland plants were removed by the 1996 and 2008 HFEs, woody riparian plants were not (Kennedy and Ralston 2011). Very little change occurred in a Glen Canyon cattail/sedge marsh as a result of the 1996 HFE (Spence 1996). Minor increases in the height and cover of vegetation were observed, along with the appearance of three nonnative species that may have been dispersed by the HFE.

Low-elevation grass and shrub species in marshes in Marble Canyon and Grand Canyon may become buried with coarse sediment, followed by recovery within 6 to 8 months (Reclamation 2011b). Coyote willow, seepwillow, tamarisk, and some low-lying grasses and forbs were partially or completely buried by sediment during the 1996 and 2008 HFEs (Kennedy and Ralston 2011). Many wetland species are adapted to burial and regrowth; some, such as cattail, common reed, and willow, thrived after burial following the 1996 HFE (Kearsley and Ayers 1999), and coyote willow recovered quickly after the 2008 HFE (Kennedy and Ralston 2011). Burial during HFEs may favor such species and alter the riparian community structure (Kennedy and Ralston 2011). Soil seed banks can be reduced, as following the 1996 HFE when approximately 45% of the seeds and 30% of the species richness of seeds available for germination in near-surface soils was lost, due primarily to burial under sediment (Kearsley and Ayers 1999). Coarsening of sand grain size on sandbars as a result of sequential

HFEs tends to favor clonal species such as arrowweed, coyote willow, and common reed (Reclamation 2011b).

Although tamarisk has increased throughout the riparian corridor since construction of the dam, HFEs do not necessarily result in the spread of tamarisk. The 1996 and 2008 HFEs occurred in spring before tamarisk seed production. Tamarisk seedling establishment was uncommon following both HFEs (Kennedy and Ralston 2011; Kearsley and Ayers 1999). Tamarisk seedling establishment could be higher if HFEs occur during the time of seed production (Mortenson et al. 2012); however, native species such as willows can also benefit from HFEs during their seed production period (Kennedy and Ralston 2011). There was no evidence of spread of camelthorn, another nonnative riparian species, in study sites after the 1996 HFE (Kennedy and Ralston 2011; Kearsley and Ayers 1999).

Low steady flows have been shown to have effects on vegetation. Low steady flows can isolate some marsh patches and cause them to dry out (NPS 2005a). Mortality of horsetail at higher elevations above the water table was 55% during low steady flows in June through August of 2000 (Porter 2002). Those flows, which were preceded by higher spring flows, also resulted in prolific tamarisk seedling establishment on recently exposed sandbars at low and intermediate elevations in the Grand Canyon due to water availability and lack of competition (Porter 2002; Ralston 2011; Mortenson et al. 2012). Seedling production of native riparian species would have occurred prior to (willows) or later than (arrowweed, mesquite, and seepwillow [*Baccharis* spp.]) the low steady flows (Ralston 2011). Native plants also became established in low-elevation areas, but at a slower rate than tamarisk, potentially by vegetative reproduction (Porter 2002; Ralston 2011).

3.6.2.1 Tribal Perspectives on Vegetation

Vegetation plays an important role in the traditional cultural ties maintained by indigenous peoples within the Canyons. The American Indian Tribes with the closest ties to the Canyons have all identified culturally important plants in the Canyons. For example, plants are perceived by the Zuni as a vital part of the landscape and are sacred to the Zuni people. All plants were given to the Zuni by the ancestral, celestial, supernatural beings. The Zuni view all plants as the offspring of Mother Earth because it was she who gave the plants to the Zuni (Stevenson 1993). Native plants at *Chimik'yana'kya'de'a* are especially sacred as a result of their association with the Zuni emergence and migration. Zuni fraternities and esoteric groups consider these plants significant because of their past and present cultural importance and usage. Today, these plants are collected and used for ceremonial, religious, subsistence, and medicinal purposes.

Zunis use literally hundreds of plants for medicinal, cultural, or religious purposes. Stevenson (1914) documented 123 plants being used for various purposes. This amount vastly underestimates the true number of plants and their respective uses, because not all the uses of all plants are known to all Zuni people. General plant usage for consumption or other everyday use is commonly known to most Zunis. However, knowledge about some plants may be possessed only by the members of a particular religious or medicine society, and in some cases specific esoteric uses may be known only by a particular Zuni individual. Plants played key roles in aiding the Zuni during their search for the middle place, as recounted in the Zuni emergence and migration narrative.

Zunis continue to rely on medicinal plants, herbs, fetishes, and other remedies that have served them through the ages. Camazine (1978) identified nearly 100 plants still used by Zunis for medical treatments. As a result of four previous monitoring trips through the Grand Canyon, the Zuni religious leaders preliminarily identified 32 plants of cultural importance in the spring during which these trips were taken; however, medicinal plants and plants with religious importance can be gathered as well during the other three seasons (winter, fall, and summer).

Hualapai monitoring programs have identified a number of issues that are negatively affecting Hualapai ethnobotanical resources along the Colorado River corridor. These include the disruption of riparian and nearshore plant ecology due to fluctuating river flows resulting from Glen Canyon Dam operations, as well as the related increased human activity that results in impacts such as trail-making and camping. Furthermore, changes in plant communities themselves are not the only causes of concern. The effects of these changes on all of the various forms of animal life that depend on plant communities for food, cover, nesting, and overall habitat must also be considered. Understanding of the intricate web of nature is often elicited through the study of Traditional Ecological Knowledge, one aspect of which acknowledges the past as a time when people and animals understood one another, and are still considered relatives

Many of the natural resources in the Canyons are considered cultural resources by the Tribes. Plants have an important role in Hopi culture; they are used in ceremonies and serve as clan totems, as medicines, in farming and food production, and for innumerable utilitarian purposes. During Hopi ethnobotanical research in the Canyons, 141 plant species were identified as culturally significant. Many important plant species specifically associated with water are found throughout the Canyons. Beyond the direct role plants play in human life, they are also recognized by the Hopi as a vital component of the ecosystem, which provides a habitat for many forms of animal life

According to the Navajo guiding principles, or teachings about plants, first and foremost, plants are people, and like people they move around, and they are male and female. To collect them, you must know them and talk with them. Even the use of plants in the food category involves prayers and offerings, which are also essential for medicinal plants. To know plants is to be familiar with the landscape, the seasons, cosmology, and the history of the area, and the movements and the genealogy of Navajo people. Plants have kept people alive. In the old days, if the corn did not grow or a drought occurred, or an enemy descended on you, knowledge of plants would guide you to water, provide nourishment, and indicate the time of the season. Like ceremonies, knowledge of plants encompasses all of these disciplines (Roberts et al. 1995). More than 57 plants that are utilized in Navajo ceremonies for traditional purposes and to support the overall health and well-being of the Navajo people have been identified in Navajo cultural resource inventory reports, as well as during annual monitoring trips (NNHPD 2015).

The many different kinds of plants that are present in and around the canyon provide food, medicine, homes, tools, and other items to the Navajo people. Many of the plants found within the Grand Canyon are considered Navajo medicines. For example, Ntl′ iz (offerings) were planted, specifically Baaashzhinii (jet), which then created nididlidii, Indian Rice Grass; the seed of this plant is black, and it is baashzhinii. Dootlizhii (Turquoise) was planted next and up grew Diwozhii Libaha; next abalone was planted and up grew Tl′ oh′ alts′ ozi; and next white shell was planted, and up grew Gahtsoh daa'. These plants provided food for sheep and horses (Roberts et al. 1995).

3.6.3 Special Status Plant Species

A number of special status plant species are known to occur along the Colorado River from Glen Canyon Dam to Lake Mead (Table 3.6-2). None of these species are federally listed, proposed for listing, or candidates for listing. Several special status species are potentially within the influence of Glen Canyon Dam operations. Satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*) are all located within the range of daily operations. The Grand Canyon evening primrose (*Camissonia specuicola* ssp. *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), giant helleborine (*Epipactis gigantea*), and lobed daisy (*Erigeron lobatus*), located above the level of daily flows but below the 45,000-cfs stage elevation, could be affected by HFEs. The main populations of the primrose, helleborine, and daisy are in springs up tributaries away from the river. Mohave prickly pear is also found in sandy flats above the 45,000-cfs stage elevation. Marble Canyon spurge (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*) are located above the level of HFEs but potentially within their influence. Sticky buckwheat (*Eriogonum viscidulum*), Geyer’s milkvetch (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*) could be affected by changes in the elevation of Lake Mead.

Several special status species occurring within the Colorado River corridor are located outside of dam operational effects (Makarick 2015) and therefore were dismissed from consideration in the impact analysis. These include Grand Canyon cave-dwelling primrose (*Primula specuicola*), Grand Canyon beavertail cactus (*Opuntia basilaris* var. *longiareolata*), Kaibab agave (*Agave utahensis* ssp. *kaibabensis*), McDougall’s yellowtops/Grand Canyon flaveria (*Flaveria mcdougallii*), Narrow phacelia/narrow scorpion weed (*Phacelia filiformis*), Desert rose/Grand Canyon rose (*Rosa stellata* ssp. *abyssa*), Canyonlands sedge/Kaibab sedge (*Carex curatorum*), Ragged rock flower (*Crossosoma parviflorum*), Button brittlebush/resin brittlebush (*Encelia resinifera*), Heermann’s buckwheat (*Eriogonum heermannii* var. *argense*), Willow glowweed/burroweed (*Lorandersonia salicina*), Ringstem (*Anulocaulis leiosolenus* var. *leiosolenus*), Chaparral yucca/Our Lord’s candle (*Hesperoyucca whipplei*), and Pillar false gumweed (*Chrysothamnus stylosus*). Sentry milk-vetch (*Astragalus cremnophylax* var. *cremnophylax*), a federally listed endangered species, is known only from the South Rim of the Grand Canyon near pinyon-juniper woodlands and therefore outside of dam operational effects.

TABLE 3.6-2 Special Status Plant Species Known to Occur along the Colorado River from Glen Canyon Dam to Lake Mead

Scientific Name	Common Name	State Status[a]	Federal Status[b]	Habitat/Location
Camissonia specuicola ssp. *hesperia*	Grand Canyon evening primrose, Kaibab suncup	None	GCNP-SC	Sandy or gravelly beaches and dry washes, often on limestone substrates (Brian 2000); located below the 45,000-cfs stage elevation, potentially affected by HFEs; Lower Granite Gorge, below Diamond Creek, Separation Canyon to Spencer Canyon (AZGFD 2013).
Eriogonum viscidulum	Sticky buckwheat	NCE	BLM-S, GCNP-SC	Mojave mixed scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Astragalus geyeri	Geyer's milkvetch	NCE	BLM-S	Creosote bush scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Arctomecon californica	Las Vegas bear poppy	NCE, ASR	GCNP-SC, BLM-S	Desert scrub; near RM 45, Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Opuntia phaeacantha var. *mohavensis*	Mohave prickly pear	ASR	GCNP-SC	River level, length of Colorado River (Brian 2000); located below the 45,000-cfs stage elevation; potentially affected by HFEs.
Erigeron lobatus	Lobed daisy, lobed fleabane	None	GCNP-SC	Rocky slopes, beaches, in sandy soils; located below the 45,000-cfs stage elevation; potentially affected by HFEs; RM 15–237 (Brian 2000).
Epipactis gigantea	Giant helleborine	ASR	GCNP-Rare	Moist soil on seepage slopes, cliff bases, along rivers, hanging gardens and seeps; located below the 45,000-cfs stage elevation; potentially affected by HFEs; from Vasey's Paradise to Grand Wash Cliffs (RM 32–277) (Brian 2000).

TABLE 3.6-2 (Cont.)

Scientific Name	Common Name	State Status[a]	Federal Status[b]	Habitat/Location
Euphorbia aaron-rossii	Marble Canyon spurge, Ross spurge	None	GCNP-Rare	Loose, sandy soil of old river bars and dunes, occasional talus slopes and rocky ledges located above the 45,000-cfs stage elevation, but potentially within influence of HFEs in Glen Canyon; also RM 3.5–53 (Brian 2000; AZGFD 2013).
Imperata brevifolia	Satintail	None	GCNP-Rare	Rocky canyons and wet places; located within the influence of daily operations, Clear Creek to Diamond Creek (RM 83.5–225) (Brian 2000).
Leersia oryzoides	Rice cutgrass	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
Lycopus americanus	American bugleweed	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
Ptelea trifoliata	Hop-tree	None	GCNRA-Rare	Located above the 45,000-cfs stage elevation, but potentially within influence of HFEs; RM –7 terrace, 1 small stand (NPS 2014b)

[a] State status codes include ASR = salvage restricted, Arizona Department of Agriculture; NCE = critically endangered, Nevada.

[b] Federal status codes include BLM-S = Bureau of Land Management sensitive; GCNP-Rare = Grand Canyon National Park rare; GCNP-SC = Grand Canyon National Park species of concern; GCNRA-Rare = Glen Canyon National Recreation Area rare; USFS-S = U.S. Forest Service sensitive.

3.7 WILDLIFE

This section describes those animal species found in the Colorado River Ecosystem downstream of Glen Canyon Dam to Lake Mead in both the riparian zone and adjacent upland vegetation communities. Along the river corridor, 90 mammals, 373 birds, 9 amphibians, 47 reptiles, and several thousand invertebrate species have been identified (NPS 2014b; Reclamation 1995; Stevens and Waring 1986b). Many wildlife species are habitat generalists, using ecosystems from both the riparian zone and upland communities to meet basic requirements. Some species are habitat specialists, requiring specific vegetation composition and structural components to meet their needs, and therefore may only occur within specific habitats within the river corridor. There is an ecological relationship between river flow and habitat for riparian and terrestrial wildlife, as illustrated in Figure 3.7-1 using birds as an example. Any changes to shoreline vegetation can affect wildlife habitat. In general, many wildlife species, including invertebrates, have benefited from increased riparian vegetation along the Colorado River corridor (King 2005).

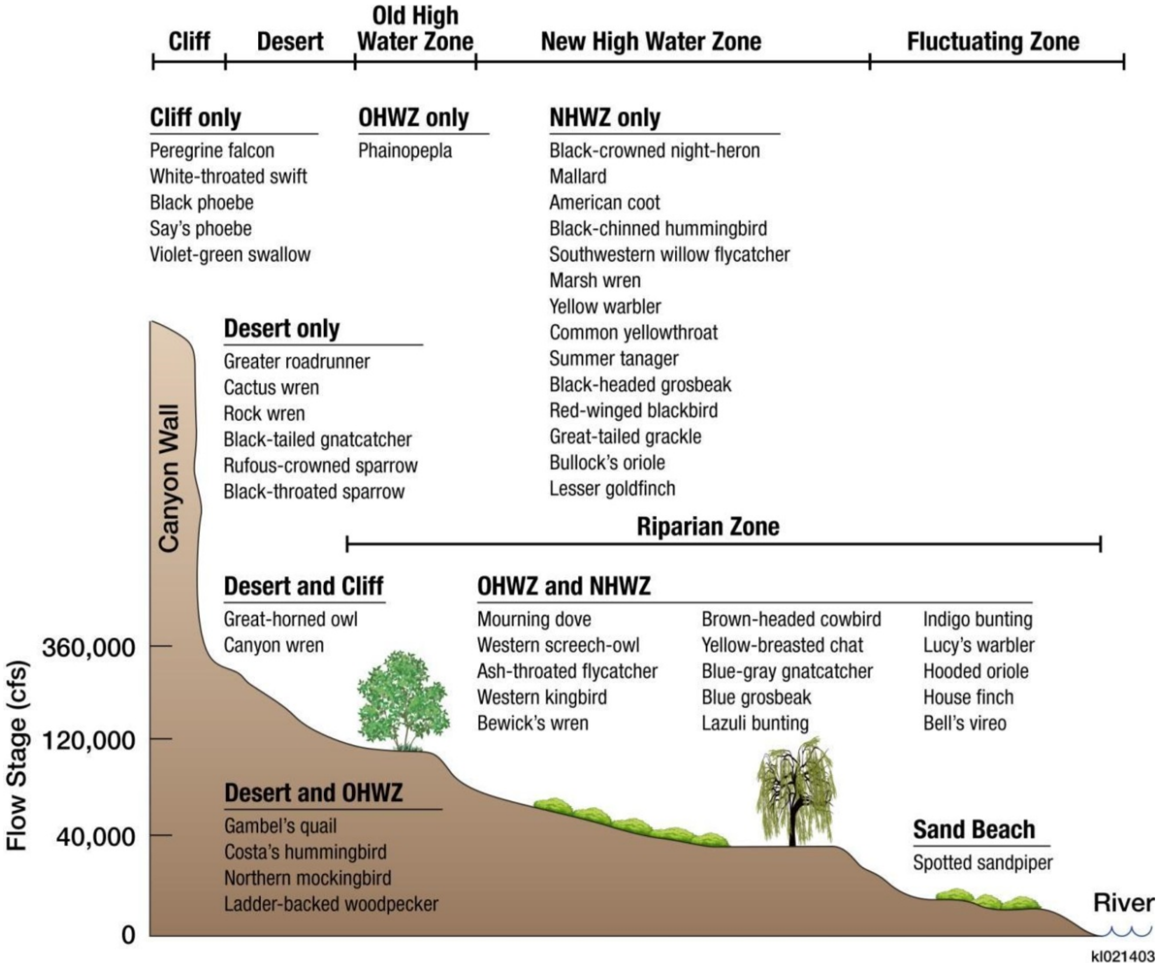

FIGURE 3.7-1 Riparian Zones Used by Nesting Birds (modified from Reclamation 1995)

3.7.1 Invertebrates

The riparian and terrestrial habitats along the Colorado River corridor through Glen, Marble, and Grand Canyons support a large and diverse invertebrate community. The increase in post-dam riparian vegetation increased the amount of habitat and forage for riparian and terrestrial invertebrates (Stevens and Waring 1986b). After construction of the dam, terrestrial insect populations were more abundant and diverse in the riparian zone than in the surrounding desert environment (Carothers and Aitchison 1976). Thousands of invertebrate species from over 260 families of arthropods are known to occur in the riparian corridor of the Grand Canyon (Stevens and Waring 1986b; Reclamation 1995). These invertebrate taxa are numerically dominated by terrestrial flies and adult forms of aquatic flies, herbivorous insects (especially cicadas, leafhoppers, and aphids), ground-dwelling forms of spiders and scorpions, beetles, and many different species of wasps, bees, and ants. These invertebrates fill a variety of ecological roles and serve as pollinators, regulate populations of other invertebrates, and provide food resources for many terrestrial and aquatic wildlife species. Invertebrates are discussed here based on the habitats they use. Threatened, endangered, and sensitive invertebrate species that may occur along the river corridor are discussed in Section 3.7.5.1.

Aquatic invertebrates downstream of Glen Canyon Dam form the food base for fish and other species at higher trophic levels. Dominant aquatic invertebrates include midges, blackflies, and the amphipod *Gammarus lacustris* (Section 3.5.1). Invertebrate species, particularly midges and blackflies, which develop in the river and emerge to complete their life cycles among riparian and terrestrial habitats, serve important ecological functions as potential prey to both aquatic and terrestrial organisms. For example, light trap sampling reveals that midge emergence peaks in lower Marble Canyon, but midge emergence is abundant throughout the river, both close to and distant from tributaries. Adult midges contribute to the terrestrial prey base from May through October (Kennedy, Muehlbauer, et al. 2014).

Most invertebrate species life cycles are entirely terrestrial. Ground-dwelling invertebrates, such as harvester ants (*Pogonomyrmex californicus*), occur at or just below the ground surface and are known to colonize camping beaches and other sandy areas. In addition to harvester ants, scorpions are also found on beaches (Carothers and Brown 1991). Before construction of the dam, annual flooding would remove invertebrate species from beach areas.

Other terrestrial invertebrates that inhabit riparian vegetation and open sand communities include cicadas, leafhoppers, armored scale insects, and robber flies. Invertebrate abundance and species richness among riparian vegetation largely depend on the supporting vegetation. For example, tamarisk is the most abundant woody plant along the river corridor, but it generally supports only four or five species of insects. Coyote willow, on the other hand, supports many species of insects. Occasional high invertebrate biomass in tamarisk communities results from outbreaks of leafhoppers (Carothers and Brown 1991), which provide an important food source for other invertebrates, amphibians, reptiles, birds, and mammals. In summer, insect biomass on tamarisk is often greater than in other riparian plant communities due to high flower numbers that attract insect pollinators. Therefore, tamarisk could increase overall biomass and diversity of arthropods (van Riper et al. 2008).

The tamarisk leaf beetle was intentionally introduced in the western United States in 2001 (Nagler and Glenn 2013) to help control or eradicate tamarisk, and were first observed downstream of Glen Canyon Dam in 2009 (Section 3.6.2). The beetle, which defoliates tamarisk, has been effective in killing large numbers of tamarisk along the river corridor downstream of Glen Canyon Dam. This die-off may have both negative and positive impacts for nesting bird species. For example, leaf beetle defoliation of tamarisk may reduce the suitability of available nest sites among tamarisk stands, but leaf beetles may also represent an important food source for birds (Nagler and Glenn 2013). However, along the Dolores River in southwestern Colorado, the diet of insectivorous birds consists of few tamarisk leaf beetles (2.1% by abundance and 3.4% by biomass) even though the beetles composed 24% and 35.4% of arthropod abundance and biomass, respectively, in the study area (Puckett and van Riper 2014).

3.7.2 Amphibians and Reptiles

More than 55 reptile and amphibian species occur downstream of Glen Canyon Dam, including 3 amphibian and 24 reptile species documented in the riparian zone of the river (Carothers and Brown 1991; Kearsley et al. 2006). The highest densities and diversity of amphibians and reptiles tend to occur in riparian areas nearer the river's edge due to the presence of water, abundant vegetation, and invertebrate food. The amphibian species along the river corridor are the canyon treefrog (*Hyla arenicolor*), red-spotted toad (*Bufo punctatus*), and Woodhouse's toad (*Anaxyrus woodhousii*) (NPS 2014c). Amphibian breeding, egg deposition, and larval development generally occur in backwaters or along the shallow water of aquatic and riparian habitats. The northern leopard frog (*Lithobates pipiens*), identified as an AZ-SGCN (AZGFD 2012), is discussed in Section 3.7.5.2.

The most common lizard species along the river corridor are the side-blotched lizard (*Uta stansburiana*), western whiptail (*Aspidoscelis tigris*), desert spiny lizard (*Sceloporus magister*), and tree lizard (*Urosaurus ornatus*) (Kearsley et al. 2006). Tree lizards use shoreline habitats proportionally more than other reptile species (Kearsley et al. 2006). Within the New High Water Zone, lizards feed on harvester ants and other insects in close proximity to the river's edge (Carothers and Brown 1991). Warren and Schwalbe (1985) noted that lizard numbers in the New High Water Zone were lowest in dense tamarisk sites. Lizards in the New High Water Zone may prefer relatively open areas such as rocks and boulders, bare soil, sand, or litter. Other lizard species, such as the zebra-tailed lizard (*Callisaurus draconoides*), may be associated with sand substrates (Stevens 2012), the availability of which can be influenced by Glen Canyon Dam flows. The high and moderate densities of lizards along the shoreline and riparian habitats, respectively, are probably due to food availability on debris along the shoreline and in riparian plants (Warren and Schwalbe 1985).

Three chelonian species occur in the area: the spiny softshell (*Apalone spinifera*), Agassiz's desert tortoise (*Gopherus agassizii*), and Morafka's desert tortoise (*Gopherus morafkai*). The spiny softshell was an introduced species into the Colorado and Gila Rivers in Arizona, and now also occurs in California, Utah, Nevada, and New Mexico (Riedle 2006). It occurs in the lower Grand Canyon/upper Lake Mead area. The Agassiz's desert tortoise (formerly known as the desert tortoise – Mojave population), a federally threatened species, inhabits the north side and west end of the Grand Canyon (NPS 2005a). It inhabits Mojave desertscrub. The Morafka's desert tortoise (formerly known as the desert tortoise – Sonoran population) occurs along the southwestern end of the Grand Canyon and around Lake Mead. It generally inhabits creosote bush flats in basins and mountain bajadas, occasionally occurring on rocky slopes. The Joshua tree forest along the rim of the Lower Gorge is an important component of its habitat (NPS 2005a). As both species spend much of their lives in burrows, neither occurs in areas inundated by Colorado River flows.

More than 20 snake species occur within the greater Grand Canyon area (NPS 2014c). The more common species in riparian areas downstream of Glen Canyon Dam include the Grand Canyon pink rattlesnake (*Crotalus viridis abyssus*), speckled rattlesnake (*Crotalus mitchellii*), black-tailed rattlesnake (*Crotalus molossus*), common king snake (*Lampropeltis getula*), and gopher snake (*Pituophis catenifer*) (Kearsley et al. 2006; NPS 2014c).

3.7.3 Birds

Spence et al. (2011) reported 316 bird species from the GCNRA, and Gatlin (2013) reported 362 species from the Grand Canyon. NPS (2014c) reported that 373 bird species have been recorded in the greater Grand Canyon region, with 250 species documented from the river corridor. Riparian habitats along the river provide breeding habitat, migratory stopover sites, and wintering areas for birds throughout the year (Spence 2006; Spence et al. 2011; Gatlin 2013). Several of the species that breed along the river corridor are considered obligate riparian species. These species include the Lucy's warbler (*Oreothlypis luciae*), Bell's vireo (*Vireo bellii*), common yellowthroat (*Geothlypis trichas*), yellow warbler (*Dendroica petechia*), yellow-breasted chat (*Icteria virens*), and black-chinned hummingbird (*Archilochus alexandri*). The brown-headed cowbird (*Molothrus ater*), a brood parasite, is also relatively common during the breeding season (Spence 2006; Spence et al. 2011; Gatlin 2013).

Birds that nest in the riparian zone along the river corridor (Figure 3.7-1) are directly and indirectly affected by Colorado River flows. River flow influences the distribution and composition of riparian vegetation, which affects invertebrate abundance (prey) and nest site availability (Carothers and Brown 1991). Only the species that nest right at the water's edge are directly influenced by fluctuating flows (Spence 2006). Important correlates with bird species richness and abundance include canopy cover, size and shape of riparian patches, and canopy volume and structure (Sogge et al. 1998; Spence 2006). The abundance of many bird species that use riparian areas (in the lower Colorado River) was highest at intermediate tamarisk levels (40–60%). In tamarisk-dominated habitats, the highest number of birds per census point occurred in areas where native vegetation composed 20–40% of the habitat. Bird numbers continue to increase with increasing amounts of native vegetation up to about 60%, but did not increase in numbers beyond that point (van Riper et al. 2008). Wintering birds did not show a significant relationship with the amount of tamarisk in the habitat. They are not strongly associated with vegetation structure but rather with habitats that provide abundant food sources of fruit and seeds (van Riper et al. 2008).

Of the 30 bird species that nest in the riparian zone, at least 23 eat insects or feed insects to their young. Other birds that do not nest in the riparian zone may still feed on insects within this zone. Yard et al. (2004) examined the diets of six insectivorous bird species along the Colorado River in GCNP. All species consumed similar quantities of caterpillars and beetles, but use of other prey taxa varied. Nonnative leafhoppers (*Opsius stactagolus*) that inhabit tamarisk made up a large portion of Lucy's warbler diets (49%); ants made up 82% of yellow-breasted chat diets; and the adult stage of aquatic midges made up 45% of yellow warbler diets. Overall, terrestrial insects made up 91% of bird diets compared to 9% of prey from adult insects that emerged from aquatic habitats (Yard et al. 2004).

The winter terrestrial bird community is diverse, with 75 species recorded. Diversity peaks in the lower portion of the Grand Canyon, particularly below RM 205 (Spence 2006). The most common wintering terrestrial species are migrants, with ruby-crowned kinglet (*Regulus calendula*) being most abundant followed by white-crowned sparrow (*Zonotrichia leucophrys*), dark-eyed junco (*Junco hyemalis*), and song sparrow (*Melospiza melodia*). Most of the winter terrestrial birds feed primarily on fruit and seeds (Schell 2005; van Riper et al. 2008).

More than 40 waterbird species inhabit the river corridor (Spence 2006; Spence et al. 2011; Gatlin 2013). Waterbirds include waterfowl (e.g., ducks and geese), wading birds (e.g., herons), and shorebirds (e.g., sandpipers and killdeers). Waterfowl are present mainly during the winter months, while wading birds and shorebirds occur primarily as migrants or during summer (Stevens, Buck, et al. 1997). The winter waterfowl density in portions of the Grand Canyon can be large; 31 species have been reported between Lees Ferry and Soap Creek, at a density of up to 250 individuals per mile (Spence 2014b). Common waterfowl species include American coot (*Fulica americana*), American widgeon (*Anas americana*), bufflehead (*Bucephala albeola*), common goldeneye (*B. clangula*), common merganser (*Mergus merganser*), gadwall (*A. strepera*), green-winged teal (*A. crecca*), lesser scaup (*Aythya affinis*), mallard (*A. platyrhynchos*), ring-necked duck (*Aythya collaris*), and Canada goose (*Branta canadensis*). Other than great blue heron (*Ardea herodias*) and spotted sandpiper (*Actitis macularia*), which are fairly common winter and summer residents along the river, wading birds and shorebirds are rare in this area (Kearsley et al. 2003; Spence 2006). Increased waterfowl numbers downstream of Glen Canyon Dam developed in response to increased aquatic productivity and open water, which provides wintering habitat for aquatic birds (NPS 2013b). Fish-eating birds in the Grand Canyon include herons, gulls, mergansers, bald eagles (*Haliaeetus leucocephalus*), and osprey (*Pandion haliaetus*) (Wasowicz and Yard 1993).

Several bird species appear to benefit from increased riparian habitat and river clarity and productivity resulting from Glen Canyon Dam operations. For example, the increase in riparian vegetation resulting from dam operations is believed to have resulted in the range expansion of breeding songbirds such as Bell's vireo (Brown et al. 1983; LaRue et al. 2001). Increases in abundance and species richness of aquatic bird populations have been attributed to increased river clarity and productivity associated with Glen Canyon Dam operations (Spence 2006). The majority of waterfowl tend to concentrate in the upper portion of the Grand Canyon due to the greater primary productivity that benefits dabbling ducks and greater water clarity for diving ducks. Recently, a large great blue heron rookery was established on both sides of the Colorado River just below Glen Canyon Dam. In May 2013, there were 22 active nests and an estimated

60 to 80 individuals. These birds benefit from the increased availability of prey from higher trout productivity of recent years and the increased water clarity. A pair of ospreys successfully nested at the base of Glen Canyon Dam in 2014 (Spence 2014a,b).

Threatened, endangered, and sensitive bird species that may occur along the river corridor are discussed in Section 3.7.5.3.

3.7.4 Mammals

More than 90 mammal species occur downstream of Glen Canyon Dam (NPS 2014c), of which approximately 34 species occur along the river corridor (Carothers and Aitchison 1976; Suttkus et al. 1978; Kearsley et al. 2006). Only three mammal species in the project area require aquatic habitats: beaver (*Castor canadensis*), muskrat (*Ondatra canadensis*), and river otter (*Lontra canadensis*). Muskrats are extremely rare in the Grand Canyon, but are occasionally observed in the Little Colorado River (Reclamation 2011d). They construct bank dens or use dens of other animals (Erb and Perry 2003). Despite occasional reports of river otters in the Grand Canyon, no reliable documentation of their presence has occurred since the 1970s (Kearsley et al. 2006). River otters are classified as extirpated in the Grand Canyon (Reclamation 2011d) despite the apparent presence of suitable habitat (Carothers and Brown 1991).

Beaver occur throughout the river corridor, from Glen Canyon Dam to the Grand Wash Cliffs where riparian vegetation is well established. Beavers cut willows, cottonwoods, tamarisk, and shrubs for food and can substantially affect riparian vegetation (Carothers and Brown 1991; Dettman 2005). For example, Mortenson et al. (2008) hypothesized that beaver may indirectly promote the invasion of nonnative tamarisk in riparian communities by preferentially feeding on native competitors such as coyote willow. Beavers in the Grand Canyon excavate lodges in the banks of the river, with the entrance located underwater and a tunnel leading up under the bank to a living chamber. Increases in the population size and distribution of beavers in Glen Canyon and the Grand Canyon have occurred since the construction of the dam. These increases are likely due to the increase in riparian vegetation and relatively stable flows (Carothers and Brown 1991; Kearsley et al. 2006).

Small mammal abundance and richness are greatest in the Old High Water Zone where steeper slopes, rock falls, and canyon wall crevices provide greater structure for wildlife habitat (NPS 2005a). Rodents (mice) are the most abundant small mammals within the riparian zone. Common species include the cactus mouse (*Peromyscus eremicus*), rock pocket mouse (*Chaetodipus intermedius*), and rock squirrel (*Spermophilus variegatus*) (Carothers and Brown 1991). The deer mouse (*Peromyscus maniculatus*) is the only mouse species that depends directly on the riparian zone (Reclamation 1995).

A least 20 species of bats are documented downstream of Glen Canyon Dam (NPS 2014c). Bats in the Grand Canyon typically roost in rock crevices, caves, and trees of desert uplands but forage on insects along the Colorado River and its tributaries. The most common bat species along the river corridor are the western pipistrelle (*Pipistrellus hesperus*), American free-tailed bat (*Tadarida brasiliensis*), pallid bat (*Antrozous pallidus*), Yuma myotis (*Myotis yumanensis*), and California myotis (*Myotis californicus*). Bats are also important prey for raptors such as the peregrine falcon (*Falco peregrinus*) (Carothers and Brown 1991).

A number of mammal species occur below Glen Canyon Dam. These include cougar (*Puma concolor*), coyote (*Canis latrans*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), American badger (*Taxidea taxus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), western spotted skunk (*Spilogale gracilis*), American hog-nosed skunk (*Conepatus leuconotus*), ringtail (*Bassariscus astutus*), and long-tailed weasel (*Mustela frenata*). Omnivorous scavengers such as the ringtail and western spotted skunk have likely increased in numbers due to an increase in riparian habitat and, more importantly, increases in campers and river runners (Dettman 2005).

Large ungulates occurring in the Grand Canyon include the desert bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus*). The Grand Canyon contains one of the largest and most continuous naturally persisting populations of desert bighorn sheep in North America (Bendt 1957; Guse 1974; Wilson 1976; Walters 1979; Holton 2014). GCNP has prioritized the need to inventory and monitor bighorn sheep, and AZGFD lists desert bighorn sheep as an AZ-SGCN (AZGFD 2012). The Navajo Nation listed this subspecies as Group 3 (highly likely to become extinct throughout its range on the Navajo Nation).

Bighorn sheep in the Grand Canyon occupy an environment that is unique relative to other desert bighorn sheep ranges. Most desert bighorn sheep populations occupy arid mountain ranges with limited (largely point) water sources and are near enough to other populations for effective dispersal and interbreeding. By contrast, bighorn sheep in the Grand Canyon live in a comparatively isolated, very deep canyon with abundant free water along the bottom (Holton 2014). Bighorn sheep routinely use free water and do not often move farther than 1.2 to 5 mi from water sources (Turner et al. 2004; Epps et al. 2007; Longshore et al. 2009). Bighorn sheep in the Grand Canyon routinely come to the river to drink and forage during the summer months (Carothers and Brown 1991). Holton (2014) reported that most ewes in the Grand Canyon remained near the river year-round, rarely moving more than a few hundred yards above the river.

Human-related barriers that restrict or eliminate dispersal to and colonization of suitable ranges affect the viability of desert bighorn sheep (Bleich et al. 1990; Epps et al. 2007). Swift wide rivers are noted to effectively delimit bighorn ranges (Graham 1980; Wilson et al. 1980; Smith and Flinders 1991). The Colorado River likely serves as a natural impediment for interbreeding and connectivity between populations (Holton 2014). Bighorn in the Grand Canyon have not been seen crossing the Colorado River since construction of Glen Canyon Dam. However, some individual bighorns have been more genetically similar to bighorn herds from the opposite side of the river, suggesting that recent ancestors crossed the river (Holton 2014). Prior to construction of the dam, seasonally low water along the Colorado River likely allowed movement across the river. Early naturalists at the Grand Canyon speculated that a bighorn, before the dam was built, could perhaps boulder-hop across the Colorado River without ever touching water. Consistent high flows of the Colorado River have likely created a formidable barrier, eliminating seasonal movements of bighorn sheep across the river and potentially restructuring the population in GCNP over the last 50 years (Holton 2014).

Studies also indicate that bighorn sheep populations may be limited through resource competition with feral burros (*Equus asinus*). In areas of sympatry, the shared foods consumed by burros may be twice the amount consumed by bighorn sheep. The burro is apparently a superior competitor compared to bighorn sheep. Following competitive equilibrium, the bighorn sheep would be relegated mainly to surviving in the most rugged habitats that could not be efficiently exploited by burros (Seegmiller and Ohmart 1981). Carothers (1977) reported that burros had affected natural communities in the three distinct plant associations (pinyon-juniper woodlands, high desert blackbrush community, and Mojave Desert vegetation type) that occur below the rims of the Grand Canyon. The most widespread impact of burro-related change was the reduction and elimination of palatable grasses and their replacement by unpalatable shrubs. Burro activity also increased soil compaction and accelerated soil loss (Carothers 1977). Burro control has been conducted in the Grand Canyon in an attempt to prevent them from denuding plateaus of grass and other forage plants consumed by native big game species such as bighorn sheep (Wright 1992). Low numbers of burros remain in the western portion of GCNP and are removed whenever possible (NPS 2005a).

Mule deer occur in relatively low densities along the river corridor as compared to the densities on the North and South Rims of the Grand Canyon. Small herds of deer are commonly seen along the river in the upper reaches of the canyon, from Buck Farm to Kwagunt Canyons. Anecdotally, mule deer have been observed swimming across the river (NPS 2014c).

3.7.5 Special Status Wildlife Species

Threatened, endangered, and sensitive wildlife species include species that may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead and that are any of the following:

- Listed or proposed for listing as threatened or endangered plant and wildlife species under the ESA (including experimental, nonessential populations) and designated and proposed designated critical habitat;
- Candidates for listing as threatened or endangered species under the ESA;
- State of Arizona Species of Greatest Conservation Need (AZ-SGCN); or
- Bald or golden eagles protected by the Bald and Golden Eagle Protection Act of 1940 (BGEPA).

Eleven threatened, endangered, and sensitive wildlife species may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead. These species and their critical habitats are discussed below.

3.7.5.1 Invertebrates

The Kanab ambersnail (*Oxyloma haydeni kanabensis*) (Table 3.7-1) is the only threatened, endangered, or sensitive invertebrate species that occurs along the Colorado River in the Grand Canyon. The Kanab ambersnail was listed as an endangered species under the ESA on April 17, 1992 (FWS 1992). However, recent evidence from anatomical and molecular genetics studies indicates that this is a geographically widespread taxon whose listing under the ESA may have been incorrect (Littlefield 2007). In a study of *Oxyloma* specimens collected from 12 locations throughout the western United States, including Kanab ambersnail from the Grand Canyon, morphometric and genetic results indicated that the Kanab ambersnail can be regarded as a member of the same species as the other *Oxyloma* populations analyzed (Culver et al. 2013). However, until this taxonomic change occurs, the Kanab ambersnail remains a listed species (FWS 2011b). No critical habitat is designated for this species.

Globally, the Kanab ambersnail is only found in three locations. Two of these are within the Grand Canyon: the riparian vegetation at Vasey's Paradise and Elves Chasm. Vasey's Paradise is at RM 31.5 and Upper Elves Chasm is at RM 116.6. The latter population was created from snails translocated from Vasey's Paradise (Sorensen and Nelson 2000; FWS 2008). The locations of these sites within the Grand Canyon are shown in Figure 3.7-2. The third location for the Kanab ambersnail is Three Lakes near Kanab, Utah (FWS 1995a).

The Kanab ambersnail lives in association with watercress (*Nasturtium officinale*), cardinal monkeyflower (*Mimulus cardinalis*), cattails (*Typha*), sedges (*Carex*), and rushes (*Juncus*). Populations within the Grand Canyon occur in areas with water sources originating from limestone or sandstone geologic strata (Spamer and Bogan 1993; FWS 1995a). The increase in cover, reduction in beach-scouring flows, and introduction of the nonnative watercress led to a >40% increase in suitable Kanab ambersnail habitat area at Vasey's Paradise compared to pre-dam conditions (Stevens, Protiva, et al. 1997).

Kanab ambersnails live 12 to 15 months and are capable of self-fertilization. Mating and reproduction occur from May to August. Subadults dominate the overwinter population. Snails enter dormancy in October–November and become active in March–April. Overwinter mortality ranges between 25 and 80% (Stevens, Protiva, et al. 1997; IKAMT 1998). During mild winters, they can continue their life cycle without dormancy or may go in and out of dormancy several times throughout the winter (Sorensen and Nelson 2002).

Based on annual survey data, live counts of Kanab ambersnails at Vasey's Paradise declined in 2011 from previous years, although the ambersnail habitat at Vasey's Paradise was in overall good condition in 2011. At Elves Chasm, live counts of ambersnails remained higher in 2011 than previous years, and habitat at this location was in good condition in 2011 (Sorensen 2012). The population at Vasey's Paradise generally occurs at elevations above 33,000-cfs flows. However, as much as 7.3% of the Vasey's Paradise population occurs below the elevation of 33,000 cfs flow and as much as 16.4% of the population occurs below the elevation of 45,000 cfs flow. The Elves Chasm population is located above the elevation of 45,000-cfs flow (Reclamation 2011d).

TABLE 3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife Species along the Colorado River Corridor between Glen Canyon Dam and Lake Mead

Common Name	Scientific Name	Status[a]	Habitat and Distribution Downstream from Glen Canyon Dam
Invertebrates			
Kanab ambersnail	*Oxyloma haydeni kanabensis*	ESA-E; AZ-SGCN	Known at only two locations within the Grand Canyon: Vasey's Paradise and Elves Chasm. These spring-fed sites occur along the river corridor. Lives in association with watercress (*Nasturtium*), monkeyflower (*Mimulus* spp.), cattails (*Typha* spp.), sedges (*Carex* spp.), and rushes (*Juncus* spp.).
Amphibians and Reptiles			
Northern leopard frog	*Lithobates pipiens*	AZ-SGCN	Presumably extirpated from Glen and Grand Canyons.
Birds			
American peregrine falcon	*Falco peregrinus*	AZ-SGCN	Common along the river corridor in summer, with about 100 pairs nesting along the cliffs of the inner Grand Canyon. Most migrate south in winter. In the Grand Canyon, common prey items in summer include riparian bird species, many of which feed on invertebrates that emerge out of the Colorado River and the adjacent riparian zone. In winter, a common prey item is waterfowl.
Bald eagle	*Haliaeetus leucocephalus*	AZ-SGCN; BGEPA	Wintering populations are known to occur in Marble Canyon and the upper half of the Grand Canyon. Wintering individuals are known to occur at tributary confluences.
California condor	*Gymnogyps californianus*	ESA-XN; AZ-SGCN	An experimental nonessential population occurs within the Grand Canyon. Releases of condors near the Grand Canyon began in 1996. The beaches of the Colorado River through the Grand Canyon are frequently used by condors for drinking, bathing, preening, and feeding on fish carcasses. An increase in interactions between condors and recreationists within the Grand Canyon has been observed.
Golden eagle	*Aquila chrysaetos*	AZ-SGCN; BGEPA	Rare to uncommon permanent resident and a rare fall migrant. Prefer rugged terrain of cliffs and mesas, and nests on cliff ledges. Migrants use sheer cliffs of the Glen Canyon area to hunt. Feeds on mammals, birds, and reptiles.

TABLE 3.7-1 (Cont.)

Common Name	Scientific Name	Status[a]	Habitat and Distribution Downstream of Glen Canyon Dam
Birds (Cont.)			
Osprey	*Pandion haliaetus*	AZ-SGCN	Large numbers use the Colorado River corridor during fall migration, usually August–September with a peak in late August. An osprey pair successfully nested near the base of Glen Canyon Dam in 2014.
Ridgway's rail (Yuma)	*Rallus obsoletus yumanensis*	ESA-E; AZ-SGCN	Casual summer visitor to marshy mainstem riparian habitats below Separation Canyon (e.g., in the Spencer Canyon and Burnt Springs areas near RM 246 and RM 260, respectively). Sight records in the study area are quite distant from its breeding range on the lower Colorado River.
Southwestern willow flycatcher	*Empidonax traillii extimus*	ESA-E; AZ-SGCN	Observed throughout the Grand Canyon in riparian habitats along the river corridor, including those dominated by invasive tamarisk. In recent years, flycatchers have consistently nested along the river corridor as new riparian habitat, primarily tamarisk, has developed in response to flow regimes. Resident birds have been documented in a small stretch of Marble Canyon and the lower Canyon near the inflow of Lake Mead.
Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	ESA-T; AZ-SGCN	Known to occur at a number of sites in the Grand Canyon near the Lake Mead National Recreation Area delta. The riparian community at these sites is primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in these sites. However, surveys for this species at these sites resulted in no detections in 2007.
Mammals			
Spotted bat	*Euderma maculatum*	AZ-SGCN	Rarely encountered throughout the State of Arizona, but may occur in areas near cliffs and water sources. Roosts primarily in crevices and cracks in cliff faces. Bats have been known to roost in cliff faces along the river corridor. Foraging may occur in riparian areas in the action area.

[a] ESA = Endangered Species Act; E = listed as endangered; T = listed as threatened; XN = experimental nonessential population; AZ-SGCN = Arizona Species of Greatest Conservation Need; BGEPA = Bald and Golden Eagle Protection Act.

Sources: AZGFD (2001c, 2002d–h, 2003b, 2006b, 2008, 2011a–b, 2012); FWS (1967; 1992; 1995a,b; 1996; 2014b); Gatlin (2013); NatureServe (2014); NPS (2015a); Reclamation (1995, 2007d).

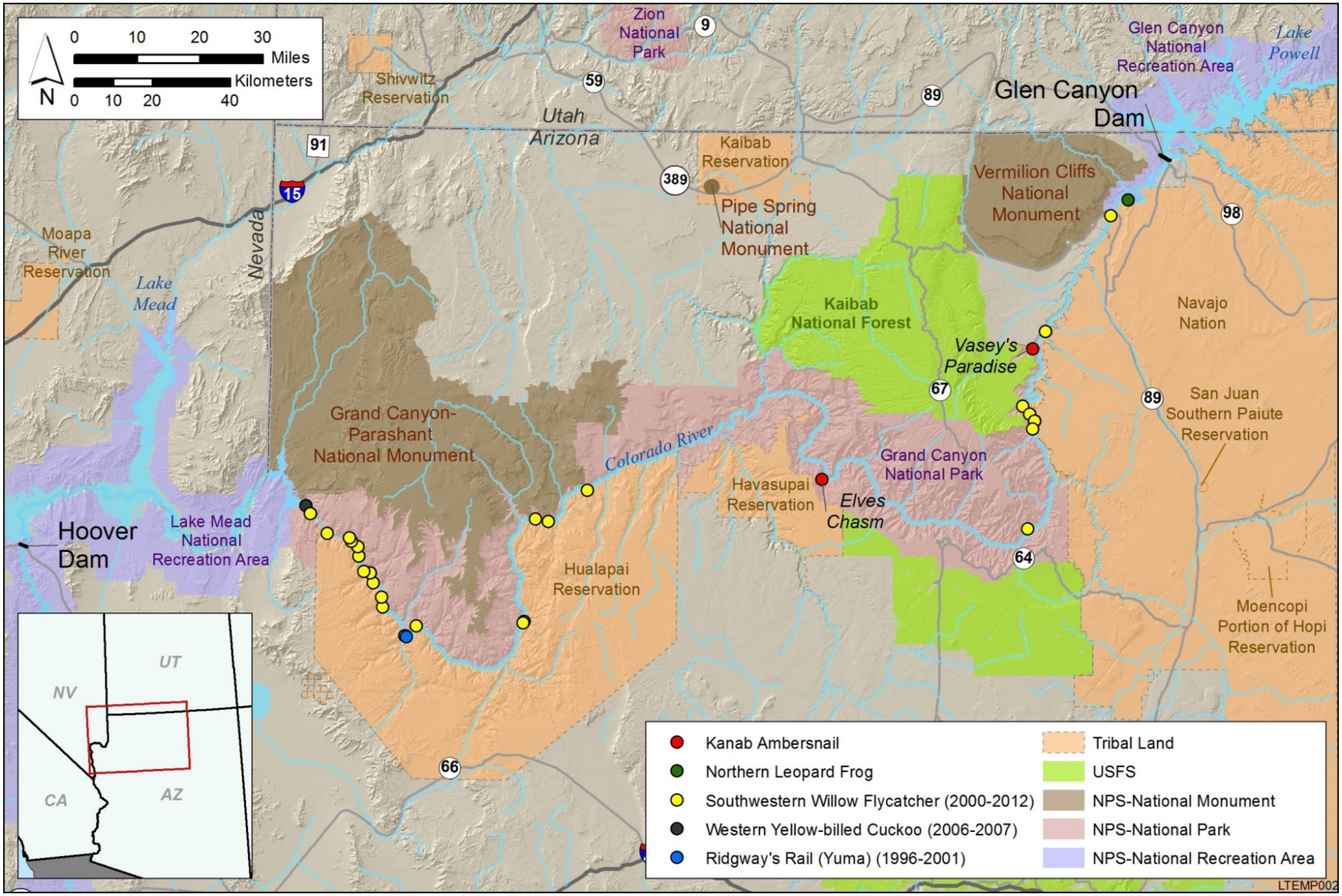

FIGURE 3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor (Sources: Drost et al. 2011; FWS 2011b; Johnson et al. 2008; NPS 2013e; Stroud-Settles 2012, 2013)

3.7.5.2 Amphibians and Reptiles

The northern leopard frog (*Lithobates pipiens*) is the only threatened, endangered, or sensitive amphibian or reptile species that occurred recently along the Colorado River downstream from Glen Canyon Dam (Table 3.7-1). Although the northern leopard frog is not listed under the ESA, it is identified as an AZ-SGCN (AZGFD 2012). In 2006, the FWS was petitioned to list the frog in 18 western states but, in 2011, the agency found that listing of this species was not warranted (76 FR 61896). The northern leopard frog occurs in northeastern and north-central Arizona in and near permanent water with rooted aquatic vegetation (AZGFD 2002h). Populations of the northern leopard frog along the lower Colorado River have declined since the construction of Glen Canyon Dam. Leopard frogs have disappeared from 70% of the known sites above and below Glen Canyon Dam, and there appear to be declines among some of the remaining populations (Drost 2005; Drost et al. 2011). Populations above the dam are declining for a number of reasons, particularly due to the introduction of nonnative fishes and changes in habitat. In years when the reservoir is full, nonnative fishes can move into tributary canyons occupied by the northern leopard frog in Glen Canyon.

The leopard frog breeds from mid-March to early June. Females lay up to 5,000 eggs. The tadpoles hatch in about a week and metamorphosis occurs in about 3 months (AZGFD 2002g). Tadpoles consume algae, plant tissue, organic debris, and small invertebrates; while adults prey on invertebrates and rarely small vertebrates (AZGFD 2002h).

The only known population of the northern leopard frog below the dam was located in Glen Canyon in a series of off-channel pools at RM 8.8 (Figure 3.7-2). Marsh habitat at this location was fed by a natural spring. Dominant vegetation included water sedge (*Carex aquatilis*) and southern cattail (*Typha domingensis*). Inundation at this site occurs at approximately 21,000 cfs. Following the experimental flood of 1996, the number of frogs at this location was estimated at a high of 177 individuals (Reclamation 2008c). Since that time, the population size has decreased. In 2004, only two adults were found (Drost 2005), and the northern leopard frog has not been observed since (Drost et al. 2011). It is assumed that the northern leopard frog population at this site has been lost due to loss of pond and marsh habitat. The species is presumed extirpated in Glen and Grand Canyons (downstream from Lees Ferry).

No listed or sensitive reptile species occur in the river corridor downstream of Glen Canyon Dam.

3.7.5.3 Birds

Threatened, endangered, and sensitive bird species that may occur in the aquatic and riparian habitats along the Colorado River downstream of Glen Canyon Dam include the American peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), California condor (*Gymnogyps californianus*), golden eagle (*Aquila chrysaetos*), osprey (*Pandion haliaetus*), Ridgway's rail (Yuma) (*Rallus obsoletus yumanensis*), southwestern willow flycatcher (*Empidonax traillii extimus*), and western yellow-billed cuckoo (*Coccyzus americanus occidentalis*). The distribution, habitat, and population trends of these species along the river corridor downstream of Glen Canyon Dam are described below and summarized in Table 3.7-1. The Mexican spotted owl (*Strix occidentalis lucida*; federally listed as threatened) is known to occur in the Grand Canyon but typically inhabits higher elevation forested side canyons above the river corridor (Bowden 2008).

American Peregrine Falcon

The American peregrine falcon was listed as endangered under the ESA on June 2, 1970. Following restrictions on organochlorine pesticides in the United States and Canada, and implementation of various management actions, including the release of approximately 6,000 captive-reared falcons, recovery goals were substantially exceeded in some areas, and on August 25, 1999, the falcon was removed from the federal list of threatened and endangered species (FWS 1999). This species is identified as an AZ-SGCN (AZGFD 2012).

Although peregrine falcons are uncommon year-round residents in the project area, the population has gradually increased since the 1970s (Carothers and Brown 1991). Peregrine falcons, which generally mate for life, nest regularly in Marble Canyon between Lees Ferry and the Little Colorado River confluence where cliffs >150 ft are abundant (Schell 2005). About 100 pairs of peregrine falcons nest along the cliffs of the inner Grand Canyon (NPS 2014c). In Arizona, peregrine falcons return to breeding areas from mid-February to mid-March, with egg laying occurring anytime from mid-March through mid-May. Fledging occurs from May to August (AZGFD 2002g). In the Grand Canyon, common prey items in summer include the white-throated swift (*Aeronautes saxatalis*), swallows, other song birds, and bats (Carothers and Brown 1991; Stevens et al. 2009). In winter, most adult falcons migrate south. For those falcons that remain for the winter, waterfowl is a common prey item (Schell 2005).

Bald Eagle

The bald eagle was originally listed as an endangered species under the ESA in 1967 and down-listed to threatened status in 1995. It was removed from the federal list of threatened and endangered species on July 9, 2007 (FWS 2007b). It is still federally protected under the BGEPA. This species is identified as an AZ-SGCN (AZGFD 2012).

A wintering concentration of bald eagles was first observed in the Grand Canyon in the early 1980s, and numbers had increased by 1985 (Brown et al. 1989; Brown and Stevens 1997). Territorial behavior, but no breeding activity, has been observed in the canyon. This wintering population was monitored through the 1980s and 1990s in Marble Canyon and the upper half of the Grand Canyon. The number of Grand Canyon bald eagles during the winter (late February and early March) ranged from 13 to 24 birds between Glen Canyon Dam and the Little Colorado River confluence from 1993 to 1995 (Sogge et al. 1995). A concentration of wintering bald eagles often occurred in late February at the mouth of Nankoweap Creek, where large numbers of rainbow trout congregated to spawn (Gloss et al. 2005). However, a flash flood destroyed the trout spawning habitat and separated the tributary mouth from the Colorado River, so the eagles no longer congregate at that tributary. Small numbers of wintering eagles (1–3) have also been noted around Bright Angel Creek, presumably also preying on nonnative fish. Since 1996, the number of wintering bald eagle observations in the Grand Canyon has declined.

California Condor

The California condor was listed as an endangered species under the ESA on March 11, 1967 (FWS 1967), and is identified as an AZ-SGCN (AZGFD 2012). By the 1930s, it was considered extirpated from the State of Arizona (NPS 2014c). A captive rearing program was initiated in 1983 to assist in recovery efforts. On October 16, 1996, it was announced that a nonessential population of condors would be established in northern Arizona (FWS 1996). On October 29, 1996, six condors were released at Vermillion Cliffs near Glen Canyon. Since that time, there have been additional releases, and the experimental population that inhabits the Grand Canyon as of September 2014 included 76 individuals (NPS 2014c). California condors are opportunistic scavengers, preferring carcasses of large mammals, but they will also feed on rodents and fish. Depending on weather conditions and the hunger of the bird, a California condor may spend most of its time perched at a roost. Roosting provides an opportunity for preening, other maintenance activities, and rest, and possibly facilitates certain social functions (FWS 1996). Nest sites often occur in caves and rock crevices (NPS 2014c).

California condors often use traditional roosting sites near important foraging grounds. Cliffs and tall conifers, including dead snags, are generally used as roost sites in nesting areas. Although most roost sites are near nesting or foraging areas, scattered roost sites are located throughout their range. California condors frequent beaches of the Colorado River through the Grand Canyon (Reclamation 2011b). Activities include drinking, bathing, preening, and feeding on fish carcasses. Condor monitors noted an increase in interaction between rafters and condors in 2002 as rafting parties sought out unused beaches for lunch stops, exploration, and close observance of condors. There have been several instances of immature condors approaching campsites.

Golden Eagle

The golden eagle is federally protected under the BGEPA and is identified as an AZ-SGCN (AZGFD 2012). It is a rare to uncommon permanent resident and a rare fall migrant throughout the region (Gatlin 2013). Preferred habitat is rugged terrain of cliffs and mesas, with nests built of large sticks on cliff ledges (NPS 2015a). Nesting has been documented from several areas of GCNRA. From November through March, the golden eagle can be observed on the high cliffs around Lake Powell (NPS 2015a). Winter aerial surveys have documented 3 to 25 individuals per survey. Since 2002, there has been a steady decline in golden eagle numbers within the Glen Canyon region (Spence et al. 2011). The golden eagle generally feeds on small mammals (e.g., rabbits and ground squirrels), but it also preys on large insects, birds, reptiles, and carrion, and can feed on mammals up to the size of small deer (NatureServe 2014; NPS 2015a).

Osprey

Although the osprey is not listed under the ESA, it is identified as an AZ-SGCN (AZGFD 2012). Reclamation (1995) stated that the osprey was a rare fall, spring, or accidental transient in the Grand Canyon. However, large numbers of ospreys now use the Colorado River corridor during fall migration, usually August–September with a peak in late August. There can be 10 to 12 individuals between Glen Canyon Dam and Lees Ferry on any given day during that period. An osprey pair nested near the base of Glen Canyon Dam in 2014 and 2015. In 2014, three eggs were laid and, although all three hatched, only one hatchling survived to fledge (Spence 2014a). One hatchling also fledged in 2015. Because nest sites are typically used for many years (AZGFD 2002f), this nest may be used in the future. The osprey feeds almost exclusively on fish, although it will also prey on snakes, frogs, shorebirds, and waterfowl (AZGFD 2002f).

Ridgway's Rail (Yuma)

The Yuma clapper rail (now known as the Ridgway's rail [Yuma]) was listed as endangered under the ESA in 1967 (FWS 1967) and is identified as an AZ-SGCN (AZGFD 2012). It inhabits marshes dominated by emergent plants. Emergent plant cover is more important than the plant species or marsh size. Areas with high coverage by surface water, low stem density, and moderate water depth are used for foraging; sites with high stem density and shallower water near shorelines are used for nesting (Reclamation 2008d). Generally, it is associated with dense riparian and marsh vegetation dominated by cattails and bulrush with a mix of riparian tree and shrub species (NPS 2013e). It is a casual summer visitor to marshy mainstem riparian habitats along the Colorado River below Separation Canyon (Figure 3.7-2). These sightings are far from the species' breeding range on the lower Colorado River (Gatlin 2013). Individuals were recorded in GCNP from 1996 to 2001. The Ridgway's rail (Yuma) was observed between Spencer Canyon (RM 246) and the GCNP boundary (RM 277), with nesting confirmed in 1996. Individuals have also been observed near Burnt Springs (near RM 260). It is not known whether cattail habitat is present in sufficient quantities to support nesting (NPS 2013e). Ridgway's rails (Yuma) feed on a variety of aquatic and terrestrial invertebrates, and on small fish and amphibians. A minor component of its diet consists of plant matter (e.g., seeds and twigs) (Reclamation 2008d). Threats to rails come from fluctuating flows during the breeding season (March–August) when there are eggs, less-mobile young birds, or flightless adults in the molting season (August).

Southwestern Willow Flycatcher

The southwestern willow flycatcher (flycatcher) is a neotropical migrant that nests in dense riparian habitats in the six southwestern states of California, Nevada, Utah, Colorado, Arizona, and New Mexico. The Pacific lowlands of Costa Rica appear to be a key winter location for the southwestern willow flycatcher, although other countries in Central America may also be important (Paxton et al. 2011). This subspecies of the willow flycatcher was listed as endangered under the ESA in 1995 (FWS 1995b). It is identified as an AZ-SGCN

(AZGFD 2012). Historically, the range of the flycatcher in Arizona included portions of all major watersheds (FWS 2002b); however, these watersheds have changed in many cases. As a result, most of the areas where flycatchers were locally abundant now support few or no individuals (FWS 2002b). Habitat and population numbers of southwestern willow flycatchers have declined in recent decades due to several factors, including loss, degradation, and fragmentation of riparian habitat; invasion by nonnative plants; brood parasitism by brown-headed cowbirds; and loss of wintering habitat (Stroud-Settles et al. 2013). Under the species recovery plan (FWS 2002b), the Colorado River downstream of Glen Canyon Dam falls within the Middle Colorado Management Unit delineated within the Lower Colorado Recovery Unit. Critical habitat for the southwestern willow flycatcher has not been designated by the FWS between Glen Canyon Dam and Lake Mead (FWS 2005, 2013b).

The southwestern willow flycatcher eats insects and needs riparian habitats to complete its life cycle. It breeds and forages in dense, multi-storied riparian vegetation near saturated soils, slow-moving water, or surface water (Sogge et al. 1995). The southwestern willow flycatcher breeds across the lower southwest from May through August (Reclamation 2007d). The southwestern willow flycatcher arrives on the breeding grounds throughout May and early June, eggs are generally laid beginning in May, and fledging occurs between June and August (Sogge et al. 1997, 2010). Occupied sites most often have a patchy interior of dense vegetation or dense patches of vegetation intermingled with openings. Most often, this dense vegetation occurs within the first 3 to 4 m above the ground (FWS 2002b). The structures of occupied patches vary, with a scattering of small openings, shorter vegetation, and open water. Occupied patches can be as small as two acres and as large as several hundred acres, but are typically >10 m wide (Reclamation 2007d).

The southwestern willow flycatcher historically nested in native plants such as willows, buttonbush, boxelder, and seepwillow (Stroud-Settles et al. 2013). It also nests in patches dominated by exotic plant species such as tamarisk and Russian olive (Sogge et al. 1997; Stroud-Settles et al. 2013). The Grand Canyon does not provide extensive stands of dense riparian habitat suited for breeding willow flycatchers. The majority of habitat patches in the Grand Canyon lack a consistent, dependable source of water for maintaining moist/saturated soil conditions and/or slow-moving or standing surface water (Stroud-Settles et al. 2013). As a result, the majority of flycatcher habitats in the Grand Canyon are marginal and, unless current hydrological conditions change, these patches will likely continue to decline. Furthermore, the recent arrival of the tamarisk leaf beetle has transformed and will continue to transform the patches of dense tamarisk into unpredictable, diminished patches (Stroud-Settles et al. 2013).

Surveys for the flycatcher have occurred in the Grand Canyon, mainly along the main stem of the river corridor, since 1982. The number of nesting flycatcher detections have declined since the 1980s, and nesting flycatchers have not been confirmed in the Grand Canyon since 2007. Except for 2008, when no nests were identified, nest surveys were not conducted between Lees Ferry and Phantom Ranch between 2007 and 2012. No nest surveys occurred between Phantom Ranch and Diamond Creek between 2005 and 2012, and no nest surveys occurred between Diamond Creek and Pearce Ferry between 2009 and 2012 (no nests were observed during surveys made in 2008) (Stroud-Settles et al. 2013). There is little information on the number of flycatchers present along the river before the construction of Glen Canyon Dam.

However, what data are available suggest that historically flycatchers were not common breeders along the Colorado River in the Grand Canyon (Sogge et al. 1997; Stroud-Settles et al. 2013). Studies conducted along the river from 1982 to 1991 and from 1992 to 2001 detected 14–15 breeding pairs per decade of surveys between Lees Ferry and Phantom Ranch (Stroud-Settles et al. 2013).

The river stretch from Lees Ferry to Phantom Ranch has been surveyed most consistently since 1982 and best represents the potential trend of the flycatcher in Grand Canyon (Stroud-Settles et al. 2013). There has been a noticeable decrease in the detection of breeding pairs since the 1990s along this stretch of river. The river stretch from Phantom Ranch to Diamond Creek has infrequent habitat patches. Surveys did not occur along this stretch until the 1990s and have produced minimal detections. The previous studies along the Diamond Creek–Pearce Ferry river stretch have varied considerably. A 5-year boost in detections along this stretch of river that occurred from 1997 to 2001 is likely due to favorable water levels of Lake Mead in combination with increased survey effort (Stroud-Settles et al. 2013). Surveys for the presence of southwestern willow flycatchers were conducted between Lees Ferry and Pearce Ferry in spring and early summers of 2010 through 2012. Ten individuals were detected during this period. All detections occurred on single occasions at a site, and not detected again in subsequent surveys. Detections were made at RMs 28.5, 50.3–50.7, 51.8–52, 183.5, 196.4, 217.6, 218, and 275. Although nest surveys were not conducted, 46 sites within the Grand Canyon were assessed for their suitability as southwestern willow flycatcher breeding habitat. Ten sites were designated as suitable habitat and 20 as potential habitat. These sites were located between RM 28.5 and RM 275 (Stroud-Settles et al. 2013).

The Colorado River corridor continues to provide essential habitat for migrating southwestern willow flycatcher, but the presence of breeding flycatchers is less common. Suitable habitat patches below Diamond Creek need to be surveyed more frequently, and any suitable sites should be at the forefront for habitat improvement and restoration work (Stroud-Settles et al. 2013).

Western Yellow-billed Cuckoo

The western yellow-billed cuckoo distinct population segment was designated as a threatened species under the ESA on October 3, 2014 (FWS 2014b). This species is also identified as an AZ-SGCN (AZGFD 2012). Proposed designated critical habitat does not occur between Glen Canyon Dam and Lake Mead. A 24-km continuous segment of the Colorado River between the upstream end of Lake Mead and the Kingsmen Wash area in Mohave County is the closest unit of proposed designated critical habitat (FWS 2014a).

The western yellow-billed cuckoo is a neotropical migrant bird that breeds and summers in northern Mexico and the western United States. Cuckoos were once considered abundant throughout the riparian floodplain along the lower Colorado River (Table 3.7-1). However, cuckoo populations have suffered severe range contractions during the last 80 years; currently western populations breed in localized areas of California, Arizona, New Mexico, western Texas, and northern Mexico, with irregular breeding in Utah and western Colorado

(Johnson et al. 2008). Factors that have contributed to population declines of the western yellow-billed cuckoo include habitat loss, fragmentation, and degradation of native riparian breeding habitat; possible loss of wintering habitat; limited food availability; and pesticide use (Johnson et al. 2010; FWS 2014a).

The western yellow-billed cuckoo requires structurally complex riparian habitats with tall trees and a multi-storied vegetative understory. It rarely nests (2.5% of nests) in areas dominated by tamarisk (Johnson et al. 2010; Schell 2005). In Arizona, western yellow-billed cuckoo occur most often in sites dominated by native tree species and at lower numbers in habitats consisting of mixed native or >75% tamarisk cover (Johnson et al. 2010). It forages almost entirely in native riparian habitat, as the large caterpillars on which it feeds depend on cottonwoods and willows and do not occur on tamarisk (FWS 2014a). It may be unreasonable to expect the Grand Canyon to serve as functional breeding habitat for the western yellow-billed cuckoo due to inadequate riparian vegetation conditions (Schell 2005). Suitable habitat may have been limited, as pre-dam floodplain terraces were neither abundant nor generally sufficiently wide in the Grand Canyon.

The western yellow-billed cuckoo is known to occur at a number of sites in the lower Grand Canyon near the Lake Mead delta (Figure 3.7-2). The riparian community at these sites is primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in these sites. However, drops in Lake Mead water levels lower the water table and stress the vegetation at these sites. Surveys for this species at these sites resulted in 29 cuckoo detections in 2006 and no detections in 2007 (Johnson et al. 2008).

3.7.5.4 Mammals

The only threatened, endangered, or sensitive mammal species that may occur in riparian areas within the action area is the spotted bat. The spotted bat is not federally listed but is identified as an AZ-SGCN (AZGFD 2012). It is rarely encountered in Arizona, but may occur in areas where cliffs and water sources are nearby. Most individuals are observed in dry, rough desert shrublands or in pine forest communities. Roost sites are presumed to be crevices and cracks in cliff faces (AZGFD 2003b). The spotted bat is active in winter, particularly if hibernacula have low humidity. It tends to be relatively solitary but may hibernate in small clusters (AZGFD 2003b). Dominant prey items are moths, but also include June beetles and sometimes grasshoppers that are taken while on the ground (AZGFD 2003b).

3.7.6 Tribal Perspectives on Wildlife

Riparian and terrestrial wildlife play an important role in Tribal culture and religion. The loss of animals or plants may have a negative cultural impact on the life of the Tribes in the region.

In the Zuni belief system, as Winston Kallestewa explained (in Dongoske and Seowtewa 2013), “All animals are our ancestors that have come back to life in a different form—

that is why all living beings, even the smallest insect, are important to the Zuni people." Dickie Shack explained (in Dongoske and Seowtewa 2013) that common animals such as lizards play a role in Ant Medicine Society prayers, prayers so ancient that they are spoken in an archaic language, learned when the Zunis were on their migration. In addition, animals, plants, and insects play a fundamental role in Zuni clan identity and collectively as Zuni people. All animals came out of the underworld with the Zunis. They are all important because they have a purpose explained in Zuni religion and cannot be killed indiscriminately. Wildlife are the spiritual beings of the ancestors for the Zuni people and are mentioned in prayers and songs (Dongoske and Seowtewa 2013). Birds are incorporated into nearly every aspect of Zuni life (Ladd 1963). Because they are viewed as messengers from the ancestral celestial beings, their appearance is closely watched. Consequently, Zunis are generally excellent ornithologists. In discussing the cultural importance of birds with Zuni cultural advisors, one becomes quickly amazed at the accuracy and consistency with which they distinguish closely related species, and are able to relate precisely the season when each species is present. Throughout the migration of the Zuni people to find the Middle Place, they were also helped by birds: a raven took the bitterness away from the corn the Zunis had harvested and made it palatable; an owl helped them by making the corn which they had harvested soft enough to eat. Although birds are probably the most important animals to Zuni, they are far from the only animals that Zunis view as religiously or culturally important. All animals have their place of reverence in Zuni cosmology (Tyler 1964). As mentioned above, even if Zunis did not need to collect any of these animals, their appearance is emblematic and auspicious of natural events, or human's response to them. During the Zunis' effort to emerge and reach the upper world, they were helped by small creatures: a locust who, like the three birds before him, attempted to reach the upper world, and a spider and a water strider who eventually direct the Zuni people to Halona-itiwana, the Middle Place. Zunis have a special relationship with water creatures, and this stems from events during their search for the Middle Place.

The Navajo perspective is that bighorn sheep, deer, wild horses, beaver, foxes, mountain lions, red-tailed hawks, owls, eagles, yellowbirds, bluebirds, black tipped birds, vultures, crows, butterflies, and many other species of wildlife were and continue to be hunted for food, ceremonial equipment, and other uses for the Navajo people. Wildlife are essential to all aspects of Navajo life. The river forms a natural boundary that protects the Navajo and helps to define the extent of Navajo land; it protects the Navajo and provides many things to Navajo people. Offerings are made to the river for protection. The water is used in a lot of ways and can lead to a good way of life for all people, and that is why people make offerings to the river. If this is not done, then the people will scatter. The offerings are much like the ones offered to the sacred mountains (Roberts et al. 1995).

For the Hopi, snakes and other reptiles play valued cultural roles in history and ceremonial activities. The presence of the Snake and Lizard clans at Hopi testifies to their ongoing importance. The Snake ceremony has its origins in the Canyons and is associated with the journeys of Tiyo down the Colorado River (Eggan 1971). Birds are a valuable cultural resource to the Hopi people. Feathers of a great many species are used in ceremonial and ritual contexts. Of particular importance are eagles, whose nests are viewed as shrines and used as receptacles for prayer offerings. Maintaining healthy populations of birds is part of the overall balance of the world.

Bighorn sheep are revered and culturally significant for nearly every Tribe with historical ties to the Grand Canyon. Historically, they were important for food, hides, and materials used in making tools and implements. The Havasupai have a close cultural affinity with the bighorn sheep and do not hunt them. The ram horns feature in the Tribal seal and Tribal identity. They furthermore figure prominently in cosmology and star lore, and are considered relatives that, when the need arises, give up their life to provide sustenance.

3.8 CULTURAL RESOURCES

Cultural resources are typically categorized as archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties, ethnographic resources, and museum collections. Many natural resources, such as plants and plant gathering areas, water sources, minerals, animals, and other ecological resources, are also considered cultural resources, as they have been integral to the identity of Tribes in various ways. For some Tribal people, archaeological resources are considered to be markers left by their ancestors, the embodiment of those who came before and are imbued with the spirits of the ancestors. They represent a physical link to the past. The physical attributes of cultural resources are often nonrenewable, especially archaeological sites, which often represent ancestral homes for the park's traditionally associated Tribes.

The National Historic Preservation Act (NHPA) is the overarching law concerning the management of historic properties on federal lands. Numerous other regulatory requirements pertain to cultural resources and are presented in Chapter 1. Historic properties are a subset of cultural resources. Historic properties are defined in the NHPA (16 USC § 470w(5)) as any "prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion on, the National Register of Historic Places, including artifacts, records, and material remains related to such a property or resource." Historic properties must be taken into consideration during the planning of federal projects. Historic properties can be either man-made or natural physical features associated with human activity and, in most cases, are finite, unique, fragile, and nonrenewable. For example, historic properties can include traditional cultural properties (TCPs), which are properties that are important to a community's practices and beliefs and that are necessary for maintaining the community's cultural identity. Historic properties can also include certain archeological sites or historic districts, such as the Lees Ferry and Lonely Dell Ranch Historic District, containing multiple interrelated archaeological or historic elements. Under the NHPA, the American Indian Religious Freedom Act, and Executive Order 13007, federal agencies are also required to consider the effects of their actions on sites, areas, and other resources (e.g., plants) that are of cultural and religious significance to Native Americans, Native Alaskans, and Native Hawaiians. Native American graves, funerary objects, sacred objects, or objects of cultural patrimony are protected by the Native American Graves Protection and Repatriation Act. Also under the GCPA, cultural resources were identified as one of the resources that must be protected, mitigated, and improved, in a manner fully consistent with and subject to Section 1802(b) of the GCPA.

Historic properties on federal lands are managed primarily through the application of laws, regulations, executive orders, and policies. Guidance on the application of these laws is provided through various means. Most federal agencies have published guidance on how to appropriately manage historic properties on their lands. Guidance for historic property management in all NPS units comes from the *NPS Management Policies 2006* (NPS 2006d) and NPS-28, *Cultural Resource Management Guideline* (NPS 1998). Park-specific guidance for GCNP and GCNRA is provided through both parks' General Management Plan and the GCNP Colorado River Management Plan (CRMP). Additional direction in GCNP is derived from the 2010 Foundation Statement and, for GCNRA, the 2015 Foundation Statement. The Reclamation policy concerning cultural resources is outlined in Policy LND P01, which ensures compliance with existing cultural resource law and Directives and Standards LND 02-01, which identifies Reclamation's roles and responsibilities as they relate to cultural resources.

The management of historic properties along the Colorado River in GCNP and GCNRA is guided by NHPA and NPS-28. Several agreements have been executed resulting from environmental studies concerning the operation of Glen Canyon Dam and the management of the resources in the two national park units. The 1995 EIS for operations of Glen Canyon Dam (Reclamation 1995) was accompanied with the signing of an NHPA Section 106 Programmatic Agreement (PA) in 1994. The agreement was among the Arizona State Historic Preservation Office, the Advisory Council on Historic Preservation, Reclamation, NPS, the Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Navajo Nation, Shivwits Paiute Tribe, and the Pueblo of Zuni. The 1994 PA addressed management of more than 300 cultural resources that could be affected by dam operations. These sites included the 323 sites that compose the Grand Canyon River Corridor Historic District. As agreed to by the signatories of the 1994 PA, a new PA is being developed in conjunction with the LTEMP EIS based on research and monitoring along the river and the resulting new information accumulated since 1996. This draft PA currently is being developed as allowed in Title 36, *Code of Federal Regulations,* Part 800.14(1) (ii) (36 CFR 800.14 b(1) (ii)) when effects on historic properties cannot be fully determined prior to approval of the undertaking. The draft PA outlines general and specific measures Reclamation (as lead federal agency for operation of Glen Canyon Dam and with responsibility for the NHPA Section 106 mitigation of effects from dam operations) and the NPS will take to fulfill their responsibilities regarding the protection of historic properties under the NHPA.

The NHPA applies to federal undertakings and undertakings that are federally permitted or funded. The regulations implementing Section 106 of the NHPA, codified at 36 CFR Part 800, define the process for identifying historic properties and for determining if an undertaking will adversely affect those properties. The regulations also establish the processes for consultation among interested parties, the agency conducting the undertaking, the Advisory Council on Historic Preservation (ACHP), State Historic Preservation Officers (SHPOs), Tribal Historical Preservation Officers (THPOs), and for government-to-government consultation between federal agencies and American Indian Tribal governments. The NHPA, in Section 106, addresses the appropriate process for mitigating adverse effects. The implementing regulations also address the process for mitigating adverse effects.

3.8.1 Area of Potential Effect

NHPA compliance includes the definition of an Area of Potential Effect (APE), which is defined in 36 CFR 800.16(d) as:

> Area of potential effects means the geographic area or areas within which an undertaking may directly or indirectly cause alterations in the character or use of historic properties, if any such properties exist. The area of potential effects is influenced by the scale and nature of an undertaking and may be different for different kinds of effects caused by the undertaking.

The undertaking is the proposed operation of Glen Canyon Dam for a period of 20 years under the LTEMP, including any related non-flow actions that could affect historic properties. Dam operations under the LTEMP are anticipated to continue to include recurring flows that may fully utilize the capacity of the powerplant turbines and bypass tubes (i.e., HFEs). The undertaking may include LTEMP activities other than Glen Canyon Dam operations (i.e., non-flow actions such as vegetation management, nonnative fish monitoring, and fish control).

Regulations by the Council on Environmental Quality (CEQ) encourage, “[t]o the fullest extent possible” that National Environmental Policy Act of 1969, as amended (NEPA) documents be “integrated with environmental impact analyses and related surveys and studies required by the . . . National Historic Preservation Act of 1966” (Section 1502.25 in CEQ 1978). Regulations by the ACHP contain similar goals (Section 800.8 in ACHP 2004). Accordingly, this LTEMP EIS describes the compliance process that is ongoing pursuant to Section 106 of the NHPA.

While the NHPA process is described in this LTEMP EIS, NHPA and NEPA each require a different consultation process, different legal standards, and different concluding documents, even though some aspects are similar. NEPA analyzes the impact of “proposed actions” and their alternatives (here, Glen Canyon Dam operations and non-flow actions identified in the LTEMP) on the “affected environment.” The “affected environment” includes a broad range of resources, such as biological, socioeconomic, aquatic, cultural, and recreation resources.

The NHPA focuses on effects on “historic properties” (properties that are eligible for or listed on the *National Register of Historic Places* [NRHP]) rather than NEPA’s focus on the effects on a broader range of resources. Specifically, the NHPA requires consultation on the potential for an “undertaking” (here, Glen Canyon Dam operations and non-flow actions identified in the LTEMP) to affect “historic properties” within a designated “area of potential effect.”

The APE for NHPA purposes may be geographically different from the affected environment for NEPA purposes. Here, several of the Tribes participating in the NHPA consultation process have indicated that the Canyons as a whole are a place of great cultural importance and requested an APE for the undertaking that extends “rim-to-rim” of the affected Canyons. This APE is geographically different than the affected environment defined in the

LTEMP EIS, and it specifically focuses on analyzing effects on historic properties rather than NEPA's analysis of the effects of an action on a broader array of resource conditions. The NHPA undertaking will be addressed within the geographic scope of the APE per NHPA standards, just as the NEPA proposed action will be addressed within the geographic scope of the affected environment per NEPA standards. A different geographic scope for the APE under the NHPA is limited to NHPA purposes and does not expand the scope of the affected environment for NEPA purposes.

For the purposes of the Section 106 process, Reclamation has defined the APE in the draft PA (available at the time of printing of this final EIS) as:

> …the area of direct or indirect effects to the character or use of historic properties on the Colorado River Corridor in Glen, Marble, and Grand Canyons from Glen Canyon Dam to the western boundary of Grand Canyon National Park, including direct or indirect effects that may be caused to historic properties by the Undertaking from rim to rim of the canyons.

There are a number of ways in which dam operations may affect cultural resources, including the periodicity of inundation and exposure, changing vegetation cover, streambank erosion, slumping, and influencing the availability of sediment. Direct and repeated inundation/exposure may affect resources such as the Spencer Steamboat, which is in the active channel (Figure 3.8-1), or Pumpkin Springs, a TCP along the bank that is subject to inundation during high flows (e.g., equalization flows and HFEs). Streambank erosion, slumping, flow-related deposition, and indirect effects of deposition may affect cultural resources contained within terrace contexts in proximity to inundated areas. Fine sand or sediment can be blown from flow-deposited source areas and deposited on cultural sites (East et al. 2016) (Figure 3.8-2). The effects of deposition or erosion may be negative or positive depending on the nature of the site. One important recent finding is that sandbars created by high-flow events at Glen Canyon Dam can provide sources of windblown sand that can cover archaeological sites (East et al. 2016) as well as anneal, or reverse, the formation of gullies (Sankey and Draut 2014). In this context, changes in dam operations can affect erosion rates on archaeological sites (East et al. 2016, Collins et al. 2016). In addition, bank deposition and aeolian transport of sediment can affect the character of other types of TCPs. The activities of research and monitoring may also have the potential to negatively affect the character-defining elements of archaeological sites and TCPs.

For purposes of this analysis, a review of sites inventoried and monitored as of 2016, and additional analysis performed by Reclamation and NPS working with USGS and GCMRC researchers using their classification system cited above,[9] it was determined that up to

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[9] USGS and GCMRC developed a system for classifying the geomorphic settings of archaeological sites, based on the degree to which they can receive windblown sand from deposits from recent HFEs, to address how archeological sites are linked to modern river processes (East et al. 2016). Surveys have documented approximately 300 to 500 archaeological sites in the river corridor of Glen, Marble, and Grand Canyons. As of January 2015, USGS had examined 358 sites in GCNP to establish the potential effects of windblown sands at these locations. This review did not include a small number of sites in GCNRA, which are expected to be classified by GCMRC in 2016.

FIGURE 3.8-1 Spencer Steamboat (Photo by Susanna Pershon, Submerged Cultural Resources Unit, NPS)

FIGURE 3.8-2 A Roasting Pit Feature (Prehistoric Food Preparation Location) in a Grand Canyon Dune

220 archeological and historic site properties could be affected by dam operations or non-flow aspects of this NEPA action. Determinations of eligibility have been completed for all known properties. Additional information, including inventory and monitoring, data recovery activities, and completion of determinations of eligibility for sites along the river, are continuing to provide up-to-date information on sites potentially affected.

3.8.2 Description of Cultural Resources and Site Types

Glen, Marble, and Grand Canyons are significant for their human history and their ongoing roles in the lives and traditions of today's American Indians of the Colorado Plateau. Archaeologists generally divide the nearly 12,000 years of human history of the Grand Canyon region into six broad periods: Paleoindian, Archaic, Formative, Late Prehistoric, Protohistoric, and Historic. The human story is represented in each of these periods along the Colorado River from Glen Canyon Dam to Lake Mead. What follows is a description of the Western Euro-American (i.e., non-Tribal) view of the types of cultural resources and the time frames into which those resources fall (see Section 3.9 for the Tribal view of the history and meaning of the Grand Canyon).

3.8.2.1 Archaeological Resources

Archaeological resources are defined as "any material remains or physical evidence of past human life or activities which are of archeological interest, including the record of the effects of human activities on the environment. They are capable of revealing scientific or humanistic information through archeological research" (NPS 2006b).

Archaeological research along the Colorado River corridor in Glen and Grand Canyons began in 1869 with the first report of ruins by John Wesley Powell (Powell 1875). In the early 1930s, professional archeology began in the region with Julian Steward's work in the Lees Ferry area (Steward 1941). Later, in 1953, Walter Taylor began work along the Colorado River in the Grand Canyon (Taylor 1958). From 1956 through 1963, one of the largest single archeological salvage projects in the United States was undertaken in the Glen Canyon region to mitigate for the construction of Glen Canyon Dam (Jennings 1966). Because dam construction predated the passage of NHPA in 1966, pre-dam mitigation was conducted under the auspices of the Historic Sites Act of 1935 and then the Reservoir Salvage Act of 1960. Pre-dam mitigation was performed by the University of Utah, the Museum of Northern Arizona, and the NPS.

For the pre-dam mitigation effort, archeological salvage was limited to the north and south sides of the Colorado River above the dam up to Hite, Utah, and to portions of the San Juan River. No survey and excavation occurred below the site of Glen Canyon Dam. A complete archaeological inventory of the river corridor, encompassing all traversable terrain between Glen Canyon Dam and Separation Canyon from the river up to and including pre-dam river terraces, was completed in 1991 for the 1995 Glen Canyon Dam EIS (Fairley et al. 1994). This and subsequent survey efforts have documented nearly 500 properties in the near-shore environment of the river from Glen Canyon Dam to Lake Mead.

To help understand what they encounter, archaeologists divide human history into sequential periods on the basis of distinctive changes in technology, subsistence practices, and/or sociopolitical organization. Below are descriptions of these periods and the types of archaeological resources typical for those periods that are found along the Colorado River from Glen Canyon to Lake Mead. The following discussion is based on chronological divisions in general use in the American Southwest, as modified for the Grand Canyon region by Fairley (2003). Details of individual sites and determinations concerning which sites could be affected and how many potential effects may be mitigated will be addressed through the PA process.

Classifications and distinctions described in this section are based on physical archeological evidence and do not incorporate ethnohistoric data. Many Tribes' oral histories and perspectives do not necessarily agree with the classifications and distinctions described in this section.

PaleoIndian Period (10,000–6,000 BC)

Sites from this time period are characterized by very distinctive spear points used to hunt large animals such as mammoth, sloth, bear, and wolf. These distinctive spear points are found across Arizona, New Mexico, and Texas. Three locations within GCNP have yielded fragmentary spear points dating from this Clovis and Folsom tradition. Three additional sites in the western Grand Canyon are also believed to contain Paleoindian artifacts. Within GCNRA, Paleoindian points have been found at six sites. Five were found in the northernmost part of the park and one west of Lees Ferry. These sites reflect characteristics of the Clovis, Folsom, and Plano technological complexes of the Paleoindian period.

Archaic Period (6,000–500 BC)

Sites dating from this time period contain smaller, but distinctive, projectile points (dart points). There is also evidence of experimentation with cultivating plants. Artifacts include small processing stones such as one-handed manos and grinding slabs, and abundant plant remains found in a trash context. These items suggest increased activities toward plant processing and more reliance on plants as a food source than was evident during the Paleoindian Period. Elaborate multicolored rock art and split-twig figurines found in cave settings are hallmarks of the Grand Canyon Archaic Period. Archaic Period sites include hunting blinds, lithic scatters at meadow edges and water holes, temporary camps, rock art, and split-twig figurine caches (Figure 3.8-3). Another distinctive aspect of the Archaic cultural history along the Colorado River corridor in GCNRA during the Archaic Period is a certain distinctive style of petroglyphs known as the Glen Canyon Linear Style (Figure 3.8-4).

Formative: Basketmaker Period (500 BC–700 AD)

This period is distinguished by extensive use of baskets, sandals, and textiles, and some important technological advancements, such as the development of the bow and arrow and the

FIGURE 3.8-3 An Archaic Period Site on the Colorado River in GCNP

FIGURE 3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA

beginnings of pottery manufacture. Habitations are often single pit houses with bell-shaped pits dug for storage. There is evidence of increased reliance on cultivated plants, primarily corn and squash. The western Grand Canyon has the largest concentration of sites from this time period within the Grand Canyon.

Formative: Ancestral Puebloan and Cohonina (700–1300 AD)

Typical of these periods are the distinctive masonry structures and apartment-like dwellings (pueblos) that the ancestral Puebloan people lived in during this time (Figure 3.8-5). This period is characterized by more permanent settlements and reliance on agriculture—most notably beans, corn, squash, and cotton—and pest-resistant storage features. Evidence of craft specialization, including distinctive ceramic designs, allows archaeologists to attribute occupation dates to sites and associated deposits with specific cultural groups. The majority of GCNRA and GCNP sites are of Puebloan age. Puebloan people were occupying the area north (Virgin Branch), south and east (Kayenta Branch) of the Colorado River during the Formative Period. Modern Puebloan Indians consider themselves to be descendants of these ancestral people.

FIGURE 3.8-5 Puebloan Era Architecture along the Colorado River in GCNP

The Cohonina people were a distinctive cultural group living in a discreet area running east to west between the San Francisco Peaks and the Grand Wash Cliffs, and north to south from the Colorado River to the Mogollon Rim during AD 700–1175. Both their home sites and distinctive ceramics identify them as culturally separate from the neighboring Puebloan groups. Cohonina sites in the Grand Canyon consist of settlements located on both sides of the river, use of multiple areas for resource procurement, and small camps or hamlets. The Hopi, Hualapai, and Havasupai consider themselves descendants of the Cohonina archaeological culture.

Late Prehistoric (1250–1540 AD)

Current evidence indicates that ancestral Puebloan populations moved out of the Canyons as the Southwest became drier and cooler in the 13th century, while people from the west continued to expand their land base and further incorporated the Canyons into their seasonal hunting and gathering cycles. These groups were less sedentary and less reliant on crops, and they lived in smaller camps, built brush structures, and used communal roasting features and small clusters of fire pits. The ancestral Pai and Southern Paiute were well established in the Canyons during this time. Archaeologists have identified different pottery types of both local and imported varieties that are characteristic of cultural transitions during this period.

Protohistoric Period (1540–1776 AD)

The Protohistoric Period contains evidence of incursions by white settlers and miners: European explorers, specifically Spanish expeditions in search of gold and wealth, but with an ancillary mission of converting native people along the way to Christianity. Although the experience of indigenous groups with these contacts varied widely, much of the region immediately in the vicinity of the Grand Canyon and Colorado River was not greatly affected, especially in the western canyon country. Growing familiarity with horses and items of European manufacture was likely, however. This period witnessed the greatest expansion of the Pai and Southern Paiute into the Grand Canyon and along the river corridor. Archaeological evidence suggests that the ancestral Puebloan peoples who had previously occupied the Canyon had already shifted settlements to the east by this time.

3.8.2.2 Historic Resources

Historic resources represent the period from 1776 to the present. The period is characterized by incursions by Europeans and later by Euro-American exploration along the Colorado River. In GCNRA, the Dominquez-Escalante Expedition in 1776 crossed the Colorado River at what is now Lees Ferry. That same year, Fr. Francisco Garces led a separate Spanish expedition from the southwest, up the lower Colorado River, and then overland; he visited Hualapai and Havasupai settlements in the western Grand Canyon area, even relying on Hualapai guides for part of his journey (Coues 1900). Euro-American expeditions include the 1869 Powell expedition and the 1889–1890 Stanton expedition, among others. The historic period ends with the engineering tests for the Marble Canyon Dam site in the late 1950s.

During the 19th century, in response to the growing pressures brought by the increasing numbers of European and Euro-American settlers, some indigenous groups retreated to smaller territories, formed aggregate villages, and used side canyons as places of refuge. Small bands of Hualapai and Southern Paiute wishing to avoid conflict with the U.S. Army stayed in western Grand Canyon, largely out of reach of soldiers on horseback. Havasupai Indians lived at Indian Garden along the Bright Angel Trail and in a permanent settlement in the South Rim Village area. Southern Paiute bands used large areas across the Tuweep Valley for habitation and resource procurement. Navajo lived along the south, east, and north rims and within the Canyon for seasonal and religious purposes. Ultimately, however, the designation of permanent reservations by treaty or executive order led to the forced or coerced relocation of Tribes out of vast areas of their ancestral territories.

Native American sites from the Historic Period in the Grand Canyon are characterized by a blending of the old and traditional with the new and innovative. Pottery and tools made of stone and bone are found along with metal and glass projectile points. Metal buckets, kitchen cutlery, and canned food and beverage containers are found in at such sites.

Types of historic resources found along the mainstem of the Colorado River include artifact caches and isolated occurrences, abandoned boats, dwellings, remnants of mining operations, camps, ranching, features related to dam site development, trails, inscriptions, and plaques. Historic era American Indian use of areas along the Colorado River is evidenced from numerous locations along the riverbanks. Remnants of hogans, extraction sites (i.e., mines) and small camps are remnants of this time. Of the total number of identified archeological sites along the mainstem Colorado River, at least 71 have a Euro-American historical component (Fairley et al. 1994; Reclamation 1995).

In GCNRA, Lees Ferry was settled by John D. Lee who established one of the primary river ferry crossings at this location (Figure 3.8-6). The remains of the Charles H. Spencer Steamboat, a steamboat launched in 1912, which transported coal to Lees Ferry, located in the bed of the river at Lees Ferry, was listed on the NRHP in 1974 as part of the Lees Ferry and Lonely Dell Ranch Historic District (Figure 3.8-1). A separate nomination was prepared for the steamboat, which was listed as an individual property in 1989. Historic campsites, corrals, and inscriptions are evidence of historic ranching and sheepherding. In response to mass unemployment during the Depression, the Civilian Conservation Corps (CCC) built structures, fire towers, and historic trail and road features that all constitute remains of activities intended to facilitate visitor use, as well as resource protection. The Marble Canyon Dam site, the physical remains of engineering tests for a dam that was not built, constitutes a significant part of the recent past. The site and related encampments have been determined eligible for listing on the NRHP.

FIGURE 3.8-6 Lees Ferry and Lonely Dell Ranch Historic District Located in GCNRA

3.8.2.3 Cultural Landscapes

As defined in the NPS *Cultural Resource Management Guideline* (NPS 1998), cultural landscapes are settings that humans have created in the natural world. They are intertwined patterns of things both natural and constructed, expressions of human manipulation and adaptation of the land (see Section 3.9 for a description of the Tribal perspective on cultural landscapes). One type of cultural landscape, the historic vernacular landscape, which is a landscape that evolved through use by the people whose activities or occupancy shaped it, is represented in the Colorado River corridor at both Lees Ferry and Phantom Ranch.

At Lees Ferry, the Colorado River briefly flows free of canyon walls, historically the only place in over 400 mi that it could be accessed on both banks by wagon. This natural attribute has influenced the site's history for 130 years. Today, historic buildings and a cemetery, shade trees, an orchard, fields, trails, and dugways carved into the river bluffs combine with more contemporary structures to illustrate the site's use as a farm and a vital ferry link between settlements in Utah and Arizona. The establishment of USGS gaging stations that are used today to fulfill terms of the Colorado River Compact, a dude ranch, and an access point for river runners are also present at Lees Ferry.

At Phantom Ranch, major side canyons and perennial tributaries provided the natural context for what would become the nexus of a cross-canyon corridor and the most popular site in the inner Canyon. Here, historic guest lodges and NPS buildings, livestock structures, cottonwood trees, a campground, bridges across Bright Angel Creek and the Colorado River, and a network of trails document 80 years of recreational activity at the very bottom of the Grand Canyon.

On a broader scale, the entire river corridor can be viewed as a cultural landscape in which American Indians for millennia have farmed, hunted, gathered plants and minerals, and performed rituals. Ancient trails, remnants of stone structures, traces of fields, and prayer objects enshrined in travertine and salt are enduring evidence of a subtly altered landscape. Integral to this landscape are the animals, plants, and minerals traditionally used and valued by American Indians. Aspects of American Indian cultural landscapes are discussed in Sections 3.8.2.4 and 3.9 and throughout this document.

3.8.2.4 Traditional Cultural Properties and Ethnographic Resources

"A traditional cultural property, then, can be defined generally as one that is eligible for inclusion in the NRHP because of its association with cultural practices or beliefs of a living community that (a) are rooted in that community's history, and (b) are important in maintaining the continuing cultural identity of the community" (Parker and King 1990). Like historic properties, TCPs are given consideration under the NHPA of 1966, as amended. During research related to Glen Canyon Dam operations and sponsored by Reclamation, five Tribes identified cultural resources of importance to them in the river corridor that are TCPs. This includes Grand, Marble, and Glen Canyons, and the Colorado and Little Colorado Rivers.

Ethnographic resources often overlap with archaeological sites and other resources of ongoing traditional cultural importance. "Park ethnographic resources are the cultural and natural features of a park that are of traditional significance to traditionally associated peoples. These peoples are the contemporary park neighbors and ethnic or occupational communities that have been associated with a park for two or more generations (40 years), and whose interests in the park's resources began before the park's establishment" (NPS 2006d).

American Indian people consider the broader area of Glen and Grand Canyons to be of traditional, even sacred, importance (Hopi CPO 2001; Dongoske 2011a; Maldanado 2011; Coulam 2011). More information regarding the perspective of the Canyons as a TCP is presented in Section 3.9. This information has been furnished by interested Tribes at the request of Reclamation and NPS, in order to aid in public understanding of their concerns.

3.9 TRIBAL RESOURCES

The Colorado River, as it flows through the Glen, Marble, and Grand Canyon (the Canyons), has a prominent place in the traditional cosmology of the indigenous peoples of the Southwest and continues to have an important place in contemporary American Indian cultures and economies. The Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes all have strong cultural ties to the Colorado River and the Canyons, and these Tribes have provided information on the determination of eligibility of the Colorado River and the Canyons as TCPs.

For these Tribes, the Canyons are more than just beautiful scenery. The Canyons are alive. The Colorado River, the canyons it has carved, and the resources it supports over a vast landscape are all considered sacred to these Tribes. Many Tribal members regard the Canyons as sacred space, the home of their ancestors, the residence of the spirits of their dead, and the source of many culturally important resources. They are important to the genesis of the Tribes and to their contemporary ways of life rooted in traditions engendered by those experiences. Many Tribes see themselves as connected to the Colorado River and its Canyons and as stewards over the living world around them, including water, earth, plant life, and animal life.

Although archaeological data can provide significant evidence of past lifeways, it tells only part of the story. Within this landscape are culturally important natural resources and significant cultural landscapes that serve as the settings for Tribal histories and spiritual narratives. Many Tribes have adapted their role as stewards to the modern environment by submitting documentation to support their contention that portions of the Colorado River and the Canyons through which it flows should be considered a TCP. Various elements within this boundary are considered contributing elements to the TCP (Hopi CPO 2001; Dongoske 2011b; Maldanado 2011; Coulam 2011). This documentation provides information supporting a determination of the eligibility of the TCP and many, but not all, associated elements located in or along the Colorado River for listing on the *National Register of Historic Places*. These TCPs have been determined eligible by the Arizona SHPO (Reclamation 2011a). Some of the elements of these TCPs have been disclosed and other elements are considered confidential, but all are considered significantly important. Traditional narratives of Tribal history and understandings of traditional landscapes, combined with archaeological data, provide a comprehensive representation of American Indian lifeways.

The following discussion of the importance of the Canyons and the Colorado River for the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes, and their monitoring of these resources was written, for the most part, by the LTEMP EIS staff and edited and approved by Tribal representatives from each Tribe. Tribal representatives from the Hopi, Hualapai, Navajo, and Zuni contributed their own text.

3.9.1 Fort Mojave Indian Tribe

The *Pipa Aha Macav*, or “people by the River” (Fort Mojave 2012), are the northernmost of the Yuman-speaking Tribes who established themselves along the banks of the Colorado River well downstream from the Canyons. Traditionally, they lived in sprawling settlements adjacent to and above the Colorado River floodplain, moving to the floodplain in the spring after seasonal floods receded. Taking advantage of fresh moist silt deposited by river flooding, they planted and harvested corn, beans, and squash, but also ranged widely, hunting, fishing, gathering mesquite, and trading. They established the Mojave Trail and participated in a trading network that stretched from the Pacific Coast to the Pueblos of the Southwest (Stewart 1983). Although they ranged widely, their cultural center remained the river, which was created by *Mutavilya* along with all plants and animals, which were drawn from the water (Fort Mojave 2012; Otero 2012). Like their upstream neighbors, the Tribe views the river as a living being to which they are connected. In the words of one Tribal member, "The river is the basis of who we are" (Otero 2012). In the Mojave worldview, members of the Tribe are related to the natural world by family ties and have stewardship responsibilities for its plants and animals. For the Mojave, some trails have spiritual as well as temporal significance. The Salt Song Trail, an important ritual trail tied to the afterlife, includes portions of the Grand Canyon.

The construction of dams along the Colorado River fundamentally changed the Mojave lifeway. No longer could they make use of the river's annual floods to refresh their fields, but even as they have adapted to changing circumstances, the river and their relationship to the natural world based on spiritual ties have remained. The Mojave continue to be concerned about the declining numbers of plants and animals in their homeland and the increase in nonnative species. Created from the water, the natural world is affected by the way the river flows. Living downstream from the project area, they are concerned about the effects of dam operation on water quality and pollution (Otero 2012).

3.9.2 Havasupai

The Havasupai Tribe and Tribal members have a history interwoven with that of GCNP since creation of the park from within the Havasupai aboriginal territory. Members of the Havasupai Tribe have access to locations of importance within GCNP guaranteed by the 1919 Act establishing Grand Canyon National Park (40 Stat. 1175, 1919) and the 1975 Grand Canyon Enlargement Act (88 Stat. 2089, 1975). The members of the Havasupai Tribe have statutory rights of access to areas on public lands, including any sacred or religious places or burial grounds, native foods, paints, materials, and medicines (16 USC 228i(c)).

The Havasupai view everything in and around the Grand Canyon as sacred in all aspects of their cultural, spiritual, and traditional life (Reclamation 1995). The Havasupai were signatories to the 1994 PA (Reclamation 1994), yet chose not to participate in the GCDAMP. The Tribe works closely with the NPS for protection of cultural sites, historic locations, and water resources. They are a member of the Native Voices on the Colorado River, a group that works with the Grand Canyon Colorado River Outfitters Association to increase understanding of Tribal relationships with the Grand Canyon from their own perspective (NVCR undated). Members of the Havasupai Tribe have worked as interpreters in GCNP.

3.9.3 Hopi

Hopi culture begins with the emergence of people into the present world from the *Sipapuni*, a spring located in the bottom of the Grand Canyon (Yeatts 2013). After emergence, the ancestral Hopi people (*Hisatsinom*) migrated in all directions around what is now the southwestern United States. During the migration period, the Hopi Clans formed and ultimately came together at the center of their universe: the Hopi Mesas. For many of the clans, the Canyons served as a home during a portion of their travels.

The Hopi ancestors have been in the Grand Canyon region for more than a thousand years (Yeatts 2013). Their presence in the Canyons (*Öngtupqa*) is well documented in the archaeological record. These ancestral archaeological sites are considered the footprints left by the *Hisatsinom* as tangible markers of their covenant with the caretaker of the earth, *Masaw*, and as a cultural claim to the land. At least 180 archaeological sites in the Colorado River corridor and in the Canyons are considered by the Hopi Tribe to be ancestral homesites.

Evidence shows that sustained use of the Canyons by the *Hisatsinom* began around A.D. 700–800 (Yeatts 2013). Use increased through time with numerous small pueblo sites dotting most of the arable land in the Canyon bottom by A.D. 1000. Both the northern and southern rims of the Canyons were similarly occupied during this time period, and a trade network extended out in all directions, linking the habitants of the Canyons to the broader region. Associated with some of these pueblos were *kivas*, ceremonial structures found in every modern Hopi village and the focus for religious activities. Just as modern Hopi villages have shrines associated with them, so do these prehistoric counterparts. While people may no longer regularly deposit offerings at these shrines, they are still considered active and sacred locations. Similarly, the sites are not considered to be "abandoned" but are still viewed as serving as the homes of those who have passed on. Proper respect for and treatment of the dead are extremely important values in Hopi culture, and protection of their resting places is paramount. The Hopi people have a spiritual obligation to serve as stewards of this land and, over the years, have developed a monitoring program that evaluates Hopi values for the health on *Öngtupqa* (the Canyons) through time (Yeatts and Husinga 2012). The Hopi are concerned with the erosion caused by the operation of Glen Canyon Dam and the effect recreation has on places of cultural importance (Yeatts and Husinga 2012). Further, and as highlighted in other sections of this document, the Hopi consider plants, animals, springs, water, landforms, minerals and other geologic deposits, and the Canyons as a whole to be sacred, contributing to the overall extreme cultural importance of the place.

3.9.4 Hualapai

The Hualapai consider the Grand Canyon and Colorado River region a great cultural landscape, especially the stretch from the Little Colorado River downstream to the confluence of the Colorado with the Bill Williams River in west-central Arizona. As of 2011, 28 places along the river are periodically monitored, in addition to an emphasis on the Colorado River itself and its tributary canyons, which the Hualapai also consider TCPs (Jackson-Kelly et al. 2011). Furthermore, many of the ancestral archaeological sites along the river are cited as TCPs, as well, but are not necessarily monitored due to difficult or obscure access and the fact that they are located in fragile contexts where periodic monitoring would simply result in undesirable impacts. Monitoring activities also include the consideration of ethnobotanical resources. When considering the intricacies of the Hualapai people's historical, cultural, and spiritual relationship to the Canyon, it is very difficult and even imprudent to attempt to assign a number to quantify significant Hualapai cultural resources along the complex landscape of the Colorado River corridor. For the most part, an evaluation of the "health" of these places is essentially a holistic response to not simply a defined point on the land, but more of the spiritual well-being one feels when standing there, as if the land was expressing its own condition through the person charged with evaluating that condition. This could include the prevalence of visitors and the availability of privacy, the incidence and cause of erosion, the quality of water, or any number of other factors. The Hualapai's participation in the monitoring and assessment of cultural and natural resources throughout the Grand Canyon extends back to the early 1990s and has been a consistent presence in management decisions.

The Colorado River and its Canyons are significant spiritual and physical landmarks for the Hualapai. The Hualapai consider the river the backbone, or *Ha'yiđađa*, of the landscape and to have healing powers (NPS 2011). Today, this is symbolized by its placement in the center of the Hualapai seal (Hualapai Tribe 2013). The Hualapai worldview holds that the Colorado River provides a life connection to the Hualapai as it flows through the landscape connecting the Canyons and the riparian ecosystems that sustain the Tribe. *Ha'thi-el* (Salty Spring), a sacred spring within the Canyons, contains a petroglyph site that tells of the creation of the Hualapai and other Pai peoples (HDCR 2010).

The Hualapai have occupied and used the lands and waters lying within their ancestral territory, including their present reservation, since time immemorial. The Hualapai traditionally benefited from both hunter-gatherer and agricultural subsistence practices. Throughout the year, the people collected various plant foods that were available depending on the season, such as agave in the spring, grass seeds in summer, and piñon in the uplands in the fall. Access to these resources often involved moving camps seasonally for closer proximity. Important cultural and spiritual lessons were passed down from elder to child during these recurring seasonal rounds (HDCR 2010). Plants were important not only for food but also for medicine and for materials for making baskets, cradleboards, shelter, and other useful items.

Although permanent water sources were sometimes scarce over large areas, the Hualapai were able to establish gardens and small fields in optimal locations, including along the Colorado River. Typical crops include corn, beans, and squash, as with other Tribes in the region. Seeds were often traded with neighboring people, especially the Mojave, Havasupai, and Hopi. Near springs, small terraces were established where water could be diverted. In larger streams, they made use of alluvial terraces that flooded over during spring runoff, enriching the soil as well as providing moisture for young seedlings. Irrigation channels were sometimes used to augment runoff and create more dependable watering systems, such as along the Big Sandy River. Unique to certain locations in the western Grand Canyon and along the lower Colorado River, such as around Pearce Ferry and Willow Beach, actual floodwater farming was practiced, similar to Ak-Chin strategies practiced in southern Arizona.

Larger game animals included mule deer, bighorn sheep, and pronghorn antelope, but rabbits and other small game were also important. Game animals provided materials for shelter, clothing, tools, weapons, and ceremonial objects, in addition to being vital food sources. The Hualapai were considered excellent hunters and commonly traded hides and dried meat with their neighbors in virtually every direction, including across the river to the north. This pattern of subsistence continued for many centuries.

Although sporadic contact with European (mainly Spanish) explorers started in 1776, it was not until the mid-19th century that Hualapai people had extensive dealings with Euro-

American settlers. At first, these interactions appeared to be fairly amicable, but as the newcomers' hunger for land, minerals, water, and grass for livestock grew, trouble ensued by the mid-1860s. After a period of conflict with these intruding Euro-American miners, ranchers, and, inevitably, the U.S. Army, a truce was forged in 1868. Most Hualapai were persuaded to congregate at Camp Beale Springs near present-day Kingman, Arizona, where they maintained relatively good relations with the commanding officer, Captain Thomas Byrne (Casebier 1980). This eventually led to a number of Hualapai men joining the Army as scouts for General George Crook in 1873, during which time they performed admirably, according to Crook's own words. However, once their service was no longer required, in 1874, many of the Hualapai were removed from their homeland and forced into an internment camp at La Paz, Arizona, near the present-day town of Ehrenberg. Many Hualapai perished from malnutrition, excessive heat, and disease while interred at the camp, and those that were eventually released returned to their homeland to find it irrevocably altered by the rush of Euro-American migration. Only those that lived in the most remote and rugged canyons near the Colorado River avoided this ordeal. The Hualapai commemorate the march to La Paz, and this tragic period of their history, through an annual relay run known as the La Paz Run (HDCR 2010).

Finally, in 1883, the Hualapai Reservation was established by executive order. It comprised just a fraction of their original territory, but included 108 mi of the Colorado River country and was at least part of their ancestral homeland. Evidence of their occupancy, use, and ownership of their ancestral territory is contained in numerous and widespread archaeological sites, family and Tribal records, oral traditions, and legends, and is embedded in the names of landmarks and sacred places throughout the Canyons and surrounding areas (Reclamation 1995). The Hualapai believe they are entrusted with the responsibility of caring for the land within their ancestral homeland, both on and off the reservation, and are actively involved in preservation activities and environmental stewardship throughout the Colorado River drainage.

The Hualapai participated in the development of the 1995 EIS (Reclamation 1995) as a Cooperating Agency and as a PA signatory. At that time, a total of 18 cultural resource sites were identified within the Canyons as archaeological sites and/or traditional cultural places associated with the Tribe, although many more have been identified since then. In addition, 46 culturally significant plant species were identified within the river corridor.

Currently, the Hualapai are active members of the Adaptive Management Working Group (AMWG) and the Technical Work Group (TWG), and they participate in the monitoring and assessment of cultural and natural resources throughout the Grand Canyon, using a combination of traditional ecological and cultural knowledge and modern survey techniques (Jackson-Kelly 2008).

Hualapai monitoring programs have identified a number of issues that are negatively affecting Hualapai archaeological sites, ethnobotanical resources, and other TCPs along the Colorado River corridor. These include the disruption of riverine ecology due to fluctuating river flows resulting from Glen Canyon Dam operations, and the related increase in human activity, such as trailing and camping on beaches near ancestral sites. The dramatic increase in the number of boaters and recreationists since the early days of river running is always a matter of concern, as evidenced by occurrences of artifact piling, trail erosion, and the occasional discovery of displaced artifacts and even human remains. The long-term trend of these phenomena presents challenges in preserving the integrity and significance of fragile and nonrenewable resources.

In April of 2010, Mr. Wilfred Whatoname, Sr., the Chairman of the Hualapai Tribe, sent a letter of testimony to the Natural Resources Committee Joint Oversight Field Hearing, entitled "On the Edge: Challenges Facing Grand Canyon National Park." The letter requested assistance in the restoration of funds for monitoring of Tribal resources and reiterated the Hualapai Tribe's commitment to preserving its natural and cultural resources (Whatoname 2010). The Hualapai are also members of Native Voices on the Colorado River (NVCR undated). The Tribe is a Cooperating Agency for the preparation of this LTEMP EIS and has continued to develop, refine, and expand its program of monitoring cultural and natural resources along the river, including further implementation of traditional ecological knowledge.

3.9.5 Navajo Nation

For the Navajo Nation, or *Diné*, the Canyons downstream from Glen Canyon Dam are culturally and historically significant. The Colorado River and Little Colorado River are seen as deities, and their confluence is associated with Changing Woman, the most important Navajo traditional deity. Navajo lore includes an account of how Haash′ cheeh Zhin., or "Humpback God," created the Grand Canyon by dragging his cane from east to west, creating a great chasm to drain a flooded world (Two Bears 2012; Roberts et al. 1995). Glen Canyon, Marble Canyon, Grand Canyon, and Little Colorado Canyon are home to many Navajo deities. Oral traditions recount how these deities bestowed important ceremonial knowledge and taught the people how to use the resources found throughout the landscape (Two Bears 2012).

Ethnohistoric accounts, as well as archaeological and linguistic evidence, suggest that the Apacheans (Athabaskan-speaking ancestors of the Navajos and Apaches) entered the North American Southwest sometime between A.D. 1000 and the 1600s. During this time, the Apacheans traded and intermarried with neighboring groups, resulting in the traditional Navajo culture of today (Brugge 1983; Brown 1991). According to traditional Navajo narratives, they have always lived "among the four sacred mountains," having emerged from the four underworlds into this world at Mount Blanca (Two Bears 2012). By the mid-1800s, the Navajo were fully utilizing resources in and around the Canyons for farming, livestock grazing, plant gathering, hunting, and religious purposes (Navajo Nation 1962, undated). The Canyons also served as a place of refuge from Mexican slave raiders, other Indian Tribes, and the U.S. Army. During the 1860s, when Navajos were conquered by the U.S. Army and interned at Fort Sumner, New Mexico, many Navajos escaped to the Canyons and lived there for many years. The Canyons continued to provide protection to the Navajo and their herds of sheep, goats, and horses during the federally imposed livestock reduction program of the 1930s and 1940s. Rivers, springs, and seeps in the Canyons have provided water to people and livestock for generations. Sites and remains of historic Navajo dwellings and sweat lodges in the Canyons retain importance for the Navajo (Roberts et al. 1995).

Both the Colorado River and the Little Colorado River protect and give life to the Navajo. Offerings seeking the rivers' protection continue to be made to the Colorado River. Floodplains have provided arable land for corn fields, and the higher terraces have provided habitat for wild game such as deer and bighorn sheep, as well as important food, medicinal, and ceremonially important plants, which continue to be used today (Roberts et al. 1995).

Many mineral sources of cultural importance to the Navajo are found in the Grand Canyon, including salt, red ochre, and quartz crystals. The salt source within the Grand Canyon is personified as Salt Woman. A journey to Salt Woman consisted of following the Salt Trail down the walls of and into the Grand Canyon, stopping periodically to make offerings and perform rituals. To enter the Canyon, an individual had to be prepared mentally, physically, and spiritually, and enter the Canyon in good faith, as it was the final resting for the spirits of their ancestors (Roberts et al. 1995).

Many of the Canyon's trails and river crossings retain important cultural meanings both ritually and historically. The stories associated with the trails keep alive traditions of Navajo history. The trails led to refuge, hunting, gathering, and trade with neighboring Tribes (Roberts et al. 1995; Linford 2000).

Nihoo′ kaa Diné é bila Ashdla′ii, or the earth surface people as referred to within Navajo society, have long since been immersed in continuing and maintaining the process of the Fundamental, Natural, and Sacred laws that were bestowed within the people since the beginning of the emergence from the first world or Ni′ Hodilil (Black World). Through the passage of each world after Ni′ Hododlizh (Blue World), Ni′ Holtso (Yellow World), and Ni′ Halgagh (White World), and finally the fifth and present world, Ni′ Hodisqous (Glittering World), the Navajo people have carried the teachings and ordinance with them as they entered the present world.

The Navajo Nation views this space as a Traditional Cultural Landscape, beginning at the Animas River, into the San Juan River, into the head waters of the Green River, into the Colorado River, Lake Powell, Glen Canyon, Marble Canyon, and Grand Canyon, through the Little Colorado River, and Lake Mead, all the way into the Gulf of California and the Pacific Ocean. This Traditional Cultural Landscape includes the tributaries within the Canyon corridors, the riparian species, wildlife, fisheries, botanical, and biological entities, insects, birds, vertebrates, and invertebrates, as well as all creatures within the Canyon as culturally significant to the Navajo people. The Colorado River and the Little Colorado River have specific functions in the ceremonial sphere of the Navajo people—the river is a protector of our people.

The Navajo have participated as a Cooperating Agency in the development of NEPA documents concerned with environmental impacts on canyon resources downstream of Glen Canyon Dam. The Navajo participated in in-depth cultural studies, which have identified important archaeological, geological, botanical, and biological resources and TCPs within the Colorado River corridor, and have provided monitoring and mitigation recommendations for culturally important resources that are affiliated with the Navajo Nation. Important cultural places include trails, subsistence areas, migration places, spiritual landscapes, and archaeological sites that lie within and adjacent to GCNRA and GCNP (Thomas 1993; Roberts et al. 1995; Neal and Gilpin 2000; NPS 2005a). Currently, the Navajo are active members of the AMWG and the TWG (Reclamation 2012b).

3.9.6 Pueblo of Zuni

The Grand Canyon and the Colorado River have been sacred to the Zuni people since their emergence onto the surface of the Earth. According to the traditional narratives that describe the emergence of the Zuni people (*A:shiwi*) from Earth Mother's fourth womb, sacred items that identify the Zuni people, the *Etdo:we* (fetish bundles), were the first to emerge; the people then came out into the sunlight world at a location in the bottom of the Grand Canyon near present-day Ribbon Falls. The creation narratives also describe the Zunis' subsequent search for the center of the world, *ldiwan'a* (the Middle Place). During this search, the people moved up the Colorado River and then up the Little Colorado River, periodically stopping and settling at locations along these rivers. At the junction of the Little Colorado and the Zuni Rivers, many of the supernatural beings, or Koko, came into existence. After a long search, the Zunis located the middle of the world and settled there. The Middle Place is located in today's village of Zuni.

The Pueblo of Zuni, the *A:shiwi,* continue to maintain very strong cultural and spiritual ties to the Grand Canyon, Colorado River, and the Little Colorado River because of their origin and migration narratives.

The Zuni River, Zuni Heaven (*Ko'lu:wa/a:wa*), the Little Colorado River, the Colorado River, and the Grand Canyon have been important to Zuni culture and religion for many centuries, if not a thousand years. Zuni religious beliefs, narratives, ceremonies, and prayers are intrinsically tied to the entire ecosystem of the Grand Canyon, including the Zunis' familial relationship with birds, animals, soils, rocks, vegetation, and water. The Grand Canyon is very sacred, and the Zuni people place prayers and offerings in the Zuni River every morning and evening which are then spiritually sent to the Grand Canyon via the Zuni River's confluence with the Little Colorado River, and the Little Colorado River's confluence with the Colorado River in Grand Canyon. The Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Grand Canyon that may have an impact on Zuni.

The Canyons have significant religious and cultural importance to the Zuni. Zuni pray not only for their own lands but for all people and all lands. To successfully carry out the prayers, offerings, and ceremonies necessary to ensure rainfall for crops and a balanced universe, Zunis must collect samples of water, plants, soil, rocks, and other materials from various locations. Each part of the Zuni universe is interconnected. Plants, animals, and colors are associated with the various cardinal directions. Minerals, clay, rocks, plants, and water are used in prayers. Prayers are accompanied by offerings of prayer sticks. The entire environment at the bottom of the Grand Canyon is sacred to the Zuni. The animals, the birds, insects, rocks, sand, minerals, plants, and water in the Grand Canyon all have special meaning to the Zuni people.

For the Zuni, traditional cultural places encompass a wide variety of cultural sites including, but not limited to, ancestral habitation sites; culturally significant archaeological/historic features; pictographs and petroglyph sites; collection areas for plants, water, and minerals; natural landmarks; prominent topographic features (e.g., mountains, buttes, and mesas); shrines; sacred sites; and pilgrimage trails and routes. All archaeological sites, including, but not restricted to, pictographs, petroglyphs, habitation areas, artifact scatters, special use areas, and other archaeological manifestations, are considered ancestral sites which imbue great cultural and religious significance to the Zuni people. For Zuni, these archaeological sites have never been abandoned but continue to maintain life and spiritual forces significant to the Zuni people. These archaeological sites are interconnected to one another by trails, and these trails connect the sites to the Zuni Pueblo. Trails often lead to shrines and offering places. Religious shrines are used by the Zuni to mark their land claim boundary, and these shrines today are considered sacred. Shrines and other sacred cultural markers act in Zuni culture as maps, charts, and other documents do in literate societies (Pandey 1995). The distribution of shrines on the landscape act as cognitive maps for the Zuni when visiting these places and play a significant role in reaffirming their cultural tradition and beliefs. Sacred shrines and offering places were used by the Zuni ancestors, the *Che:be:ya:nule:kwe* and the *Enoh:de:kwe*. Sacred shrines and offering places are often related to archaeological sites and are of great cultural and religious significance. These shrines and offering places are also imbued with life and spiritual forces. Shrines hold great significance to the Zuni and are considered sacred.

Shrines are also established at other places of significance within the Zuni cultural landscape. The Zuni people preserve and maintain these “markers,” or locations, by making regular visits or pilgrimages to deposit offerings and to ask blessings upon the land. Their location is central to the purpose of the shrines. Thus, to disturb or move the shrines would be incompatible with the essence of their location with respect to the areas and the people they protect. Second, these locations have religious significance to the Zuni people, whether or not they appear to have been used recently. Once established, they continue to provide their protection in perpetuity.

The Zunis have many named places across their cultural landscapes that are interconnected by a series of trails. Trails are important because they maintain strong and continuous connections between the heart of the Pueblo of Zuni and many culturally important distant places on the Zuni landscape. Trails are blessed before their use, and once blessed, they are blessed in perpetuity. For the Zuni, there are many prayers and offerings that are required to be made prior to a trip and during a trip, along the trail to the place of emergence and the Grand Canyon. Prayers and offerings are made at springs and shrines along the trail. The trail, the springs, and the shrine area are all sacred. The trail from Zuni to the Grand Canyon thus has a continuously important religious meaning to the Zuni people. It is sacred and will also be used in the afterlife. Once a trail is blessed, it remains blessed permanently. The Zuni people have important concerns regarding the ancient Zuni trail from their village to the bottom of the Grand Canyon.

The Pueblo of Zuni participated in the development of the 1995 EIS (Reclamation 1995) as a Cooperating Agency and a PA signatory. Currently, the Pueblo of Zuni has active representation on the AMWG and the TWG. The Zuni religious leaders, on behalf of the Pueblo of Zuni, have developed a monitoring program to identify impacts on important Zuni cultural resources in the Colorado River corridor resulting from the operation of Glen Canyon Dam. Erosion and visitor impacts (i.e., trailing, litter, vandalism, and unauthorized artifact collection or movement) have been identified as sources of impacts on archaeological sites and areas of cultural importance (Dongoske 2011a). The results of monitoring are presented directly to Reclamation and NPS.

On September 21, 2010, the Zuni Tribal Council passed resolution M70-2010-C086 which stated that the Zuni Tribe of the Zuni Indian Reservation "... asserts that the Grand Canyon, from rim-to-rim, and all specific places located therein including the confluence of the Colorado and Little Colorado Rivers, topographic and geologic features, springs, archaeological sites, mineral and plant collection areas, and any other places it so identifies as historically, culturally, or spiritually important to the Zuni Tribe within the Grand Canyon must, as a matter of the United States government's trust responsibility toward the Zuni Tribe, be assumed by all federal agencies to be eligible for the National Register of Historic Places and insists that all agencies of the United States Department of the Interior (a) accept and respect the above assertion with reference to any topographic or geologic feature, water body, or other place identified by the Zuni Tribe as historically, culturally, or spiritually important within the Grand Canyon; (b) respect Zuni tribal interests in and values ascribed by the Zuni Tribe and tribal members to such places; and (c) accept and respect that the continued mechanical removal of rainbow and brown trout at the confluence of the Colorado and Little Colorado Rivers is considered an adverse effect on a traditional cultural property that is eligible for listing on the National Register of Historic Places."

Appended to the Zuni Tribal Council Resolution was a Position Statement by the Zuni religious leaders. The Position Statement asserted that the *Newe:kwe*, *Makeyana:kwe*, *Uhuhu:kwe*, *Chikk'yali:kwe*, *Shuma:kwe*, *Halo:kwe*, *Sahniyakya*, *Shiwana:kwe*, Zuni Rain Priests, Zuni Kiva Groups, and other associated religious societies demonstrate their passionate support for the Pueblo of Zuni's cultural and religious objections (to mechanical removal of rainbow and brown trout), reflected in a letter from Zuni Governor Cooeyate to Mr. Larry Walkoviak, Regional Director, Bureau of Reclamation, dated June 30, 2010, on the past and proposed future mechanical removal management activities that consist of electroshocking and destroying thousands of rainbow trout and brown trout at the confluence of the Little Colorado River and Colorado River in the Grand Canyon. It is the Zuni religious leaders' position that all animals, including all aquatic life (e.g., native and nonnative fishes, insects, amphibians, snakes, and beavers), birds, plants, rocks, sand, minerals, and the water in the Grand Canyon are sacred, have special meaning, and a unique familial relationship to the Zuni people. The entire environment at the bottom of the Grand Canyon is sacred to the Zuni people and the Grand Canyon, including the confluence of the Little Colorado River and Colorado River, which are integrally connected to Zuni religious beliefs, ceremonies, and prayers.

The Zuni annual ceremonial activities carried out at Zuni are performed for the specific purpose to ensure adequate rainfall and prosperity for all life in the universe. The individual Zunis that are part of these respective Religious Societies pray, fast, and perform religious ceremonies not only for Zuni lands, but for all people and all lands. The ceremonies are performed as part of maintaining a balance with all parts of this interconnected universe. As a direct consequence of maintaining this balance and interconnectedness with the universe, the Zuni religious leaders believe that the past and proposed future mechanical removal activities created, and will continue to create, a counter-productive energy to the Zuni respective ceremonial efforts to ensure rainfall, prosperity for all life, and to maintain a harmonious balance among the Zuni people. The Zuni religious leaders expressed that they were especially concerned that the continuation of the mechanical removal activities proposed for the confluence of the Little Colorado and Colorado Rivers within the Grand Canyon magnifies the negative effects of this action for the Zuni people and all life. The Grand Canyon is very sacred, and the Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Grand Canyon that may have an impact on the Zuni.

In summary, the Zuni River, Zuni Heaven (*Ko'fu:wa/a:wa*), the Little Colorado River, the Colorado River, and the Canyons have been important to Zuni culture and religion for many centuries. Zuni religious beliefs, narratives, ceremonies, and prayers are intrinsically tied to the entire ecosystem of the Canyons, including the Zuni's familial relationship with birds, animals, soils, rocks, vegetation, and water. The Canyons are very sacred, and the Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Canyons that may have an impact on the Zuni.

3.9.7 Southern Paiute Tribes

The Southern Paiute Tribes that have ties to the region and who are most directly tied to the project area include the Kaibab Band of Paiute Indians; the Paiute Indian Tribe of Utah, which consists of five bands of Southern Paiute (Cedar Band, Indian Peaks Band, Kanosh Band, Koosharem Band, and Shivwits Band); and the San Juan Southern Paiute. The Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah are also members of the Southern Paiute Consortium (SPC). The Kaibab Band represents the SPC in matters pertaining to Glen Canyon Dam and Colorado River management. Currently, the SPC is an active member of the AMWG and the TWG, and the San Juan Southern Paiute Tribe is a member of the AMWG (Reclamation 2012b).

The Canyons and the Colorado River have historic cultural significance as well as contemporary interest to the Southern Paiute. Traditional narratives of Paiute origin vary from band to band, but share a general central theme: "Southern Paiutes were the first inhabitants of this region and are responsible for protecting and managing this land along with the water and all that is upon and within it" (Bulletts et al. 2012).

The Southern Paiute maintain that when an undertaking is to occur in their traditional homeland, it is their divine right to understand that action and the impacts that could occur from that action (Stoffle et al. 1997). This is the reason the Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah formed the SPC in 1993 and participate in the management of lands throughout the Colorado River drainage, through improved government-to-government interaction in the GCDAMP. The consortium participates in and conducts its own assessments of potential environmental impacts on ethnobotanical, geological, biological, and cultural resources, the results of which are provided in technical reports (Bulletts et al. 2012).

According to traditional Southern Paiute values, all plants, animals, and natural elements within that land should be respected and protected. The Southern Paiute have identified the Colorado River as one of their most powerful natural resources and consider the Colorado River corridor, as well as all natural and cultural resources within the corridor, as culturally significant features (Stoffle et al. 1995). The Southern Paiute have identified numerous archaeological sites, rock art sites, animal resources, ethnobotanical resources, traditional natural resources (soil, water, rocks, and minerals), and traditional and contemporary use areas within the Colorado River corridor that require monitoring and protection (Stoffle et al. 1994). Resources of importance continue to be monitored by the SPC on a rotating basis (Austin et al. 1999; Drye et al. 2000, 2001, 2002, 2006; Bulletts et al. 2003, 2004, 2008, 2010, 2011, 2012; Snow et al. 2007).

3.9.8 Indian Trust Assets and Trust Responsibility

The DOI acknowledges its federal trust responsibility and the importance of Indian trust assets within the proposed action area. The trust responsibility consists of the highest moral obligations that the United States must meet to ensure the protection of Tribal and individual Indian lands, assets, resources, and treaty and similarly recognized rights. Secretaries of the Interior have recognized the trust responsibility repeatedly and have strongly emphasized the importance of honoring the United States' trust responsibility to federally recognized tribes and individual Indian beneficiaries (Secretarial Order 3335; DOI 2014). Indian trust assets are legal interests in property held in trust by the U.S. Government for Indian Tribes or individuals. Examples of such resources are lands, minerals, or water rights.

The action area is bounded on the east by the Navajo Indian Reservation and on the south by the Hualapai Indian Reservation. The DOI and Reclamation have ongoing consultation with these Tribes regarding potential effects of the proposed action on their lands, resources, trust assets, and reserved rights. High-flow releases will inundate shoreline areas historically affected by seasonal floods, and analysis of effects on resources show that the proposed action is not likely to impact Indian lands, minerals, or water rights.

3.10 RECREATION, VISITOR USE, AND EXPERIENCE

This section describes the recreational and visitor-experience attributes found in the portions of GCNRA, GCNP, and LMNRA that are related to flows of the Colorado River. Recreational use is an important issue because the GCPA mandates that Glen Canyon Dam be operated in a manner that protects, mitigates adverse impacts to, and improves the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use, and in a manner fully consistent with and subject to 1802(b) of the GCPA. Most of the description provided here focuses on resources and activities found in the Colorado River Ecosystem from just below Glen Canyon Dam within GCNRA to the western boundary of GCNP at RM 277. In addition, because of the potential for the alternatives to differentially affect seasonal (though not annual) reservoir levels of both Lake Powell in GCNRA and Lake Mead in LMNRA, this section also provides information on visitor use of both reservoirs and reservoir recreational facilities, principally boat launching facilities, that could be affected by the alternatives being evaluated. Recreation economics are discussed in Section 3.14 of this EIS.

3.10.1 Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area

The Glen Canyon reach of the Colorado River is an approximately 15-mi segment of the river between Glen Canyon Dam and Lees Ferry. Recreational activities include trout fishing, motor- and human-powered boating, commercial flat-water rafting, camping, photography, hiking, interpretation of historic and cultural properties, and sight-seeing.

The Glen Canyon General Management Plan (GMP) (NPS 1979) established management zones within GCNRA. The majority of the land along the Glen Canyon reach is located within the Natural Zone and is included in the park's wilderness recommendation. The river is managed to provide for recreation. Visitor services include facilities for camping and interpretation of resources (such as the descending sheep panel). The Navajo Indian Reservation extends along much of the east side of the river immediately adjacent to the GCNRA boundary.

3.10.1.1 Lees Ferry Recreational Fishery

The 15-mi Glen Canyon reach, upstream of Lees Ferry, supports a recreational fishery that is an important recreational and economic resource based largely on nonnative rainbow trout (Figure 3.10-1). Fish in all waters within GCNRA and GCNP are managed by the NPS, in coordination with the AZGFD and FWS. The condition of the recreational rainbow trout fishery within GCNRA can be affected by the operations of Glen Canyon Dam, which is operated by Reclamation. The Comprehensive Fisheries Management Plan (the Plan) for GCNP and GCNRA (NPS 2013e) identified the goals for this fishery (Section 1.10.3).

Dam operations and fishery management may affect the size and quality of the rainbow trout fishery and angler satisfaction. While there is a strong interest in maintaining the highly valued trout fishery in the Glen Canyon reach, there also is concern about the migration of trout to downstream areas, particularly near the confluence with the Little Colorado River, which is a key concentration area for the humpback chub, a federally listed endangered species.

The recreational fishery has evolved over time. From 1964 until 1991, the rainbow trout population of the Glen Canyon reach was sustained by annual stocking, but with the stabilization of flows by dam operations, the trout population eventually became self-sustaining, although stocking was continued through 1998. The trout population in the Glen Canyon reach has been monitored on a regular basis by the AZGFD since 1991. Key population characteristics identified

FIGURE 3.10-1 Glen Canyon Reach Rainbow Trout (Courtesy of George Andrejko, AZGFD)

from 1991 to 2009 inform an understanding of the relationships among dam operations, the trout population, and native fish populations (Makinster et al. 2011).

The trout population and accompanying angler success rate in the Lees Ferry fishery has been quite variable over the years in response to management actions, stocking, dam release regimes, and food availability. The periods from 1972 to 1978 and 1978 to 1984 were known as the fishery's Trophy Era and Quality Era, respectively (Reclamation 1995). It was during this time that the Lees Ferry fishery achieved an international reputation as the fishery producing 10- to 20-lb trout, and bag limits of 10 fish weighing a total of 40 lb were not uncommon. From 1978 to 1984, the number of large fish being taken declined, but creel census reports still showed an average weight of 2.79 lb for fish caught, and fish over 20 in. in length made up about 25% of the catch. From 1985 to 1988, fish longer than 20 in. made up less than 10% of the harvest and the percentage of 15-in. fish harvested continued to increase (Reclamation 1995). Section 3.5.3.1 presents additional discussion of the condition of the rainbow trout fishery.

An estimated total of 10,908 anglers used the trout fishery in 2014, of which 6,739 were boat anglers and 4,169 were walk-in anglers. Creel surveys conducted during 2014 found that overall angler success remained high, with 95% and 64% of the anglers catching at least one fish in the boat-fishing section upriver of Lees Ferry or walk-in section accessed at Lees Ferry, respectively. Angler satisfaction on a scale of 1 to 5 remained high for both boaters and walk-in anglers, averaging 4.55 and 4.28, respectively (Rogowski, Winters, et al. 2015). The angler catch rate generally correlates with the size of the fish population; Figure 3.10-2 shows the angler catch rate from 1977 to 2014. Catch rates peaked in 1998 and increased sharply again after 2010, with 2012–2014 having the highest catch rates on record for boat anglers. Catch rates for boat anglers have been roughly twice the rates of walk-in anglers in recent years. This has been attributed to the ability of boat anglers to access preferred trout habitat; walk-in angling catch rates are better correlated to those from electrofishing surveys (Rogowski, Winters, et al. 2015). Electrofishing data from 1991 to 2014 show that there has been a long-term trend of decreasing fish size. In the 2014 electrofishing survey conducted in the Glen Canyon reach in spring, summer, and fall months, 17% of rainbow trout collected were less than 152 mm (6 in.) in length, 58% were in the 152–305 mm (6–12 in.) range, 24% were in the 306–405 mm (12–16 in.) range, and only about 1% were in the >405 mm (>16 in.) range (Rogowski, Winters, et al. 2015).

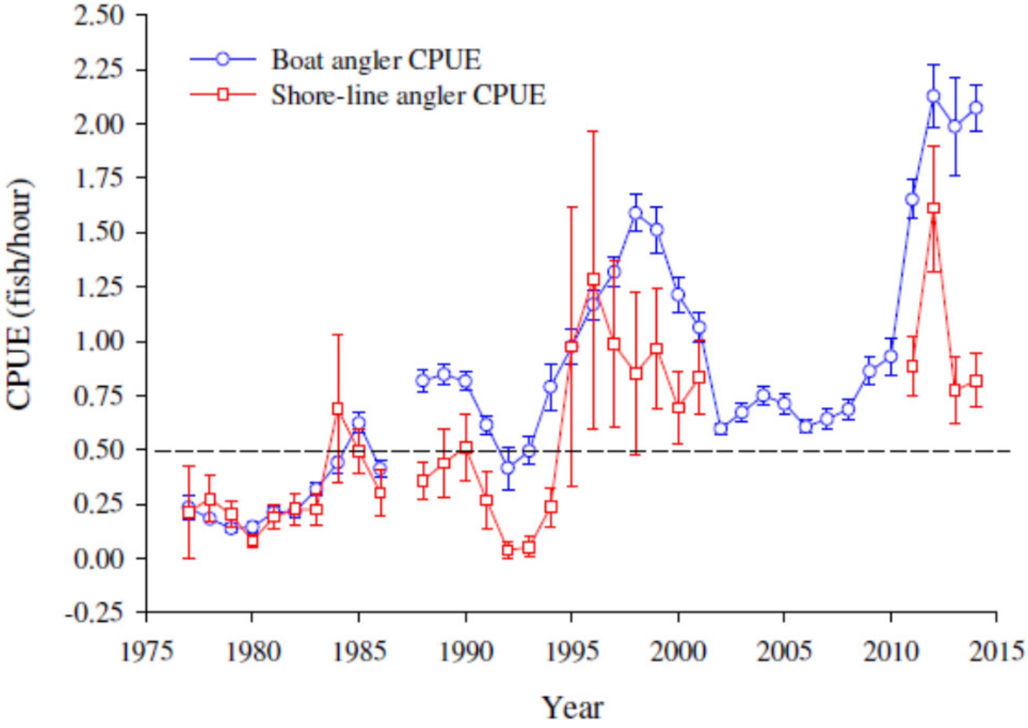

FIGURE 3.10-2 Mean Rainbow Trout Catch Per Unit Effort (CPUE, fish caught per hour) of Both Boat Anglers (blue) and Shore-Line Anglers (red) from Creel Surveys at Lees Ferry (Error bars represent 95% confidence intervals. The dashed line indicates the trigger point [0.5 fish/hour] for potential restocking of rainbow trout) (Source: Rogowski, Winters, et al. 2015)

Levels of Recreational Fishing Use

Fishing occurs year-round in the Glen Canyon reach, with the months of April and May being the peak months; however, substantial fishing use occurs from March through October in most years (Figure 3.10-3). Most fishing in the Glen Canyon reach is done from boats or is facilitated by boating access to gravel bars and riffles in the river upstream from the NPS Lees Ferry launching facility (Anderson, M. 2012). Fly fishermen fish both from boats and by wading bars, riffles, and along the shore, depending on river flow levels; spin fishermen more typically fish from boats. The availability of gravel bars for wading depends on river flow, with most bars being inundated at 15,000–16,000 cfs (Lovett 2013). There also is significant fishing use by walk-in anglers along the approximately 1.2 mi of shoreline between the Paria River confluence with the Colorado River and just upstream of the launch facility. A significant number of anglers also access the Colorado River below the Paria River confluence on Paria Beach, farther

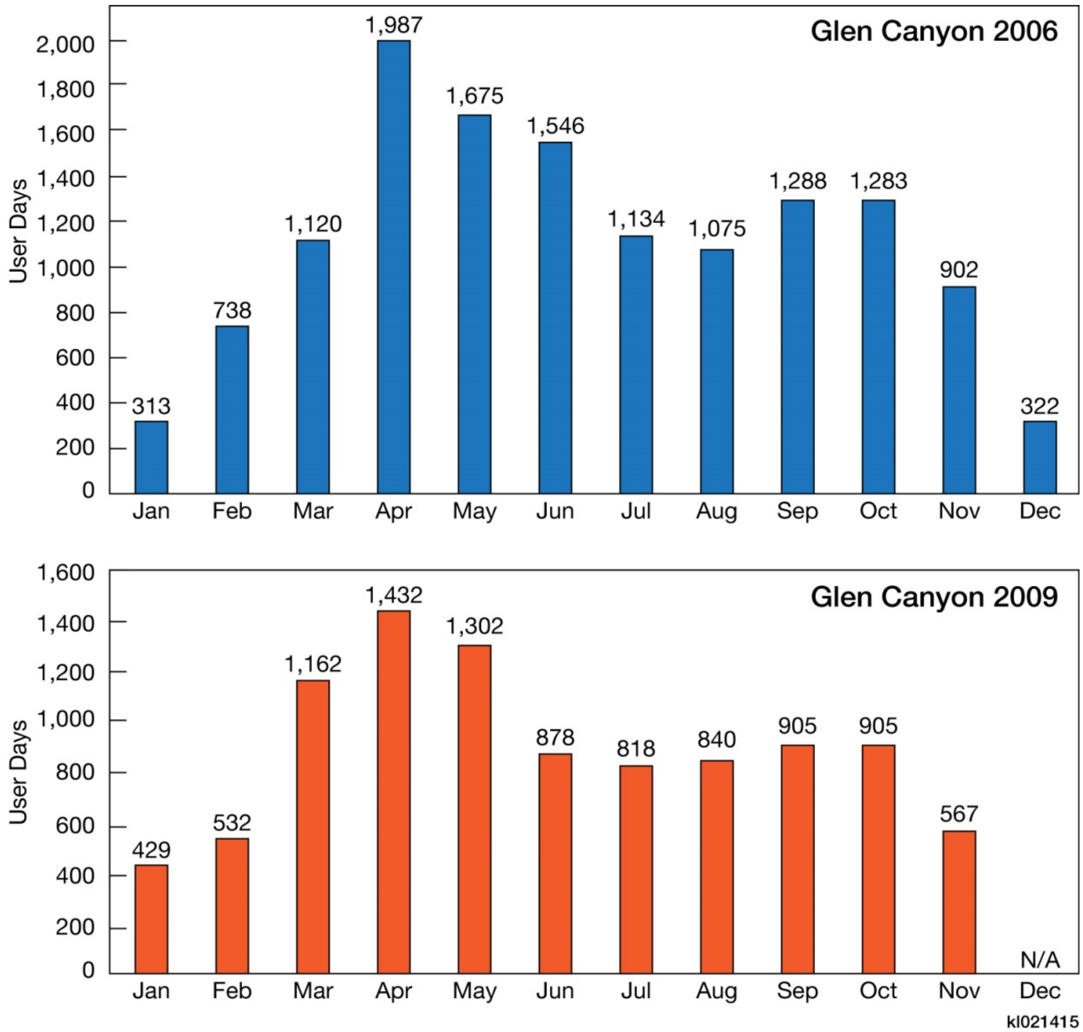

FIGURE 3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 (top) and 2009 (bottom) (User days for December 2009 were unavailable.) (Source: Reclamation 2011d)

downriver via a system of trails and across the river on Navajo Nation land. Power boaters can access almost the entire river upstream of the launch facility with only a small safety area below the dam being closed to access.

The AZGFD estimates that total fishing use in the Glen Canyon reach in 2011 was 87,000 hr (15,818 angler days)[10] (Anderson, M. 2012). It is estimated that 70,000 hr (12,727 angler days) of angling effort were expended by boating anglers and 17,000 hr (3,091 angler days) were expended by walk-in anglers. Angler use days peaked at 52,000 in 1983 (Figure 3.10-4), but eventually dropped to an average of about 3,400 angler days per year from the mid-1990s to 2009.

Based on AZGFD survey data, commercial guided fishing operations provided services for about 50% of the boating-based fishing use in the Glen Canyon reach in 2011 (Anderson, M. 2012). In that year, there were five NPS-authorized commercial fishing guide operations in the Glen Canyon area that provided boats and guide services in the Glen Canyon reach (Blaise 2012). The AZGFD surveys did not identify any walk-in fishing use being supported by commercial guides. NPS requires guide services to obtain a commercial use authorization to operate in GCNRA; guide services are also required to report the number of anglers they serve. The total reported number of commercial clients for the five commercial fish

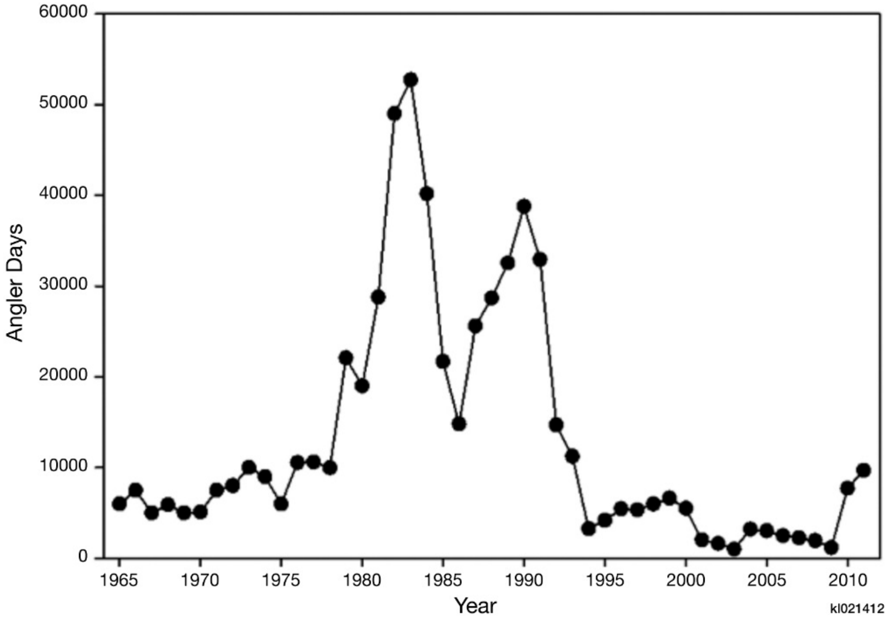

FIGURE 3.10-4 Angler Days in the Glen Canyon Reach from 1965 through 2011 (Source: AZGFD 2012)

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[10] The methodology for calculating angler days depends on the assumed duration of an angler day. The computations here are based on the AZGFD statewide standard of 5.5 hr per trip, but it is understood that if other durations were used, the number of angler days would be somewhat different.

guiding operations in the 4 years beginning in 2009 was 2,652, 2,665, 2,731, and 3,210, respectively (Blaise 2012; Seay 2013). Historical levels as high as 4,000 clients per year reported for a single operator provide some perspective on the current level of commercial use (Gunn 2012).

Important Attributes of Fishing in the Glen Canyon Reach, and Angler Satisfaction

The quality of the fishing experience in the Glen Canyon reach has been studied to help understand what characteristics of fishing in the area are most important to participants. A study was conducted by Bishop (Bishop et al. 1987), during the period when dam operations resulted in large and rapid fluctuations in water flows, and shortly thereafter, when the trout fishery was regularly producing large fish. Stewart et al. (2000), in another study, identified the flow regimes preferred by anglers. Although the two studies were completed under very different operating criteria, anglers in both studies identified a marked preference for flows in the 8,000 to 15,000 cfs range. The Bishop et al. (1987) study further identified a preference for steady, non-fluctuating flows. In the Stewart et al. (2000) study, fluctuating flows were not identified as an issue. Because fluctuations had been reduced to MLFF levels by the time of the study, attitudes toward higher levels of fluctuations could not be investigated. In both studies, anglers showed a clear dislike of flows below 3,000 to 5,000 cfs.

Another attribute of fishing in the Glen Canyon reach affects fishermen who wade and fish from the shore and gravel bars. High water levels, as well as rapid changes in water levels, directly affect the safety of wading fishermen due to the potential for being swept away by the river current. The 1995 Glen Canyon Dam EIS (Reclamation 1995) included a reference to three drownings that were possibly related to river stage or stage change and noted that high flows (30,000 cfs or more) reduced the safety of wading in the river. After the adoption of the MLFF operating protocol in 1996, ramping rates were restricted, which has likely reduced the level of this risk, as has the reduction of normal high flows to 25,000 cfs.

3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon Reach

The 15-mi Glen Canyon reach supports several recreational activities in addition to fishing, including river floating, camping, and recreational boating. In calendar year 2012, the NPS estimated that 210,627 recreation users visited the area (NPS 2014d). About 25% of the annual visitors accessed the Glen Canyon reach via the pontoon-raft concession that departs from near the dam and travels to Lees Ferry.

The NPS facilities at Lees Ferry consist of launch ramp, campground, restroom, and interpretive facilities, as well as hiking trails. Upstream of the Lees Ferry launching facility, there are six designated, boat-accessible-only, camping areas.

An NPS launching facility is the main access both for trips going downstream through the Grand Canyon and for fishermen and other boaters heading upstream into the Glen Canyon reach. Other facilities nearby interpret the human history and existing historic structures associated with the historic Lees Ferry crossing. Aside from the courtesy dock located next to the launch ramp, facilities in this area are not directly affected by river fluctuations.

Camping in the Glen Canyon reach is allowed in six designated areas. These areas are located on sediment terraces and beaches. Figure 3.10-5 shows the general location of the six designated campsite areas; Figure 3.10-6 illustrates the affected shoreline environment in the GCNRA area.

In addition to recreational power boating, the NPS authorizes one concessionaire, Colorado River Discovery (CRD), to provide a variety of river services in the Glen Canyon reach. The most popular of these is a half-day guided trip that originates at the dam; most CRD trips are motorized pontoon rafts; however nonmotorized full-day trips are also offered.

The most popular trips are run twice a day during the main part of the recreation season. The rafts have a maximum capacity of 22 people (Figure 3.10-7). At the end of the trip, passengers are transported by bus from Lees Ferry back to Page. The passenger numbers served by CRD are shown in Table 3.10-1. The trips generally originate in Page, Arizona, at the company's rafting headquarters. The company provides transportation to the launch site, which involves traveling through a 2-mi-long tunnel that provides access to the river near the base of the dam. CRD also offers a "backhaul" service that transports private canoes/kayaks upstream from Lees Ferry into the Glen Canyon reach.

HFEs create operational issues for the rafting concessionaire, including cessation of operations for a period of days and the need to move mooring docks and rafts or to relocate operations to the Lees Ferry launch site, which is a less economically desirable location.

Although the concessionaire does not operate during an HFE, the departure/mooring docks for the day-rafting operation are located just below the dam, and HFEs in excess of power-plant capacity of 31,500 cfs require that the concessionaire's rafts either be removed from the river or relocated because of turbulence caused by the discharge from river bypass tubes. The concessionaire also must remove boarding steps that allow passengers to get from the dock to the boats. With 21 boats, this is a major amount of work that disrupts business operations.

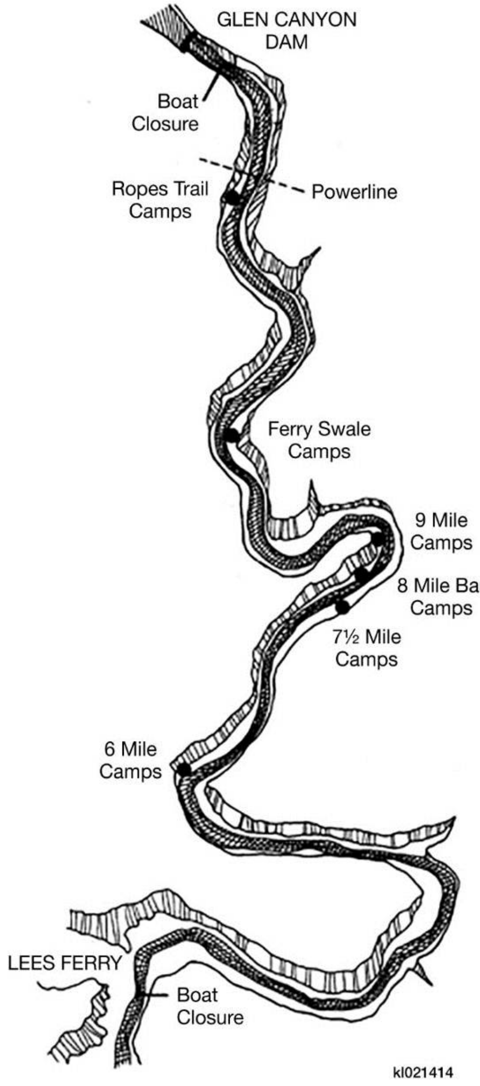

FIGURE 3.10-5 Designated Campsite Areas in the Glen Canyon Reach (GCNRA 2014)

FIGURE 3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach Ferry Swale Campsite (courtesy of GCNRA)

FIGURE 3.10-7 Pontoon Raft Operated by Colorado River Discovery

TABLE 3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–2013

Month	2009	2010	2011	2012	2013[a]
January	0	0	0	0	0
February	159	8	19	48	100
March	2,211	2,131	1,922	2,163	2,416
April	5,256	4,599	4,533	4,801	3,914
May	6,346	6,629	6,831	7,438	6,684
June	9,333	9,905	9,444	10,372	8,880
July	9,256	9,887	9,389	9,515	8,661
August	7,866	7,367	7,050	7,773	6,479
September	5,415	6,287	6,001	6,300	5,245
October	3,825	3,824	3,978	4,363	1,311
November	735	687	458	535	562
December	0	0	0	0	8
Totals	50,402	51,324	49,625	53,308	44,260

[a] The 2013 passenger counts were affected by the closure of AZ Highway 89 in February 2013.

Source: Blaise (2014).

During the 2012 HFE event, the concessionaire indicated that the business was disrupted for 2 days before and after the HFE, as well as during the HFE.

In cases of extended high flows (such as 1983–1984), rafting operations have been relocated to the Lees Ferry launch site where they continued limited and modified operations. These operations require the rafts to travel upriver against heavy current with a reduced passenger load. In this scenario, the rafts travel upriver through a portion of the canyon using an outboard motor before floating back down to the starting point (Grim 2012). During high-flow events (other than scheduled HFEs), docking at Lees Ferry is more difficult than normal because the dock is actually in the river channel, as opposed to being out of the main current. Departing from Lees Ferry rather than the dam keeps the business functional to some degree, but the economics of this type of operation are unfavorable compared to normal operations.

River fluctuations were identified as an issue for both anglers and white-water boaters in previous studies (Bishop et al. 1987; Stewart et al. 2000). However, both studies found that daily river level fluctuations had no impact on the satisfaction level for day-rafting clients.

HFEs create steep banks in some portions of the river that make access from boats to the upper sediment terraces more difficult, as shown above in Figure 3.10-6 (Grim 2012; Hughes 2014a). Eventually most steep areas are eroded by use, restoring easy access to the terraces, but in some locations, the banks have been steepened to such a degree that visitor access is adversely affected. The six designated recreation sites located on these sediment terraces are shown above in Figure 3.10-5.

3.10.2 The Colorado River in Grand Canyon National Park

GCNP is a world-renowned recreational destination that was designated as a World Heritage Site in 1979. The 1,217,261-ac park contains 1,143,918 ac proposed for wilderness designation, including 10,919 ac of potential wilderness along the Colorado River corridor. Annual visitation to the park has exceeded 4 million visitors since 1992, and 5.5 million visitors were recorded in 2015. Most visitors focus on the developed facilities on the South Rim of the canyon, where the majority of the visitor services, facilities and administrative offices are located.

While GCNP is a destination for millions of visitors, the focus of this EIS is on the Colorado River corridor, which constitutes a small percentage of the acreage of the park and small portions of both Glen Canyon and Lake Mead National Recreation Areas. The CRMP, completed in 2006 (NPS 2006b), set goals for managing visitor use and protecting resources along the river corridor. The CRMP established a visitor capacity based on the number, size, and distribution of campsites; natural and cultural resource conditions; and visitor experience. The NPS established a capacity of 60 trips at one time, which is managed through daily launch limits, group size, and trip length. The CRMP also established a 6.5-month no-motors season to provide enhanced wilderness opportunities. The CRMP outlines a Research, Monitoring, and Mitigation Program that manages resources in the river corridor within an adaptive management framework (NPS 2006c).

A whitewater trip through all or part of the Grand Canyon is a rich and complex recreational experience, valued for the sights and sounds of the canyon, the whitewater, and superb opportunities for varied recreational experiences. Recreational river use in the Grand Canyon expanded from 150 people per year in 1955 to 16,500 in 1972 and to the 2006 CRMP levels of about 24,657 visitors per year.

Visitor use is measured in user days (e.g., one person on the river for a day), and is managed to offer a variety of trip types throughout the year. Trips are conducted using a variety of types and sizes of boats and rafts; group sizes can range up to 32 people (including guides); trip lengths range up to 25 days; trips can be run by commercial companies or by private individuals; and there are various means of joining trips, including launching from Lees Ferry, hiking into or out of the canyon to join or leave a trip at Phantom Ranch, and limited access by vehicle and helicopter (commercial use only) to join trips in the western portion of the Grand Canyon.

Commercial river trips are offered from April through October, and noncommercial trips occur year round. Peak use occurs in May through September, as shown in Figure 3.10-8.

Most Grand Canyon river trips begin at Lees Ferry (RM 0) and take out at Diamond Creek (RM 226) or at Pearce Ferry (RM 280) in LMNRA. When Lake Mead water levels were higher prior to the onset of drought in 2000, trips also regularly ended at South Cove (RM 295) on Lake Mead. Prior to the drought, reservoir travel began at Separation Canyon, and many trips either motored or were towed by jet boats that came upriver from Lake Mead to their take-out points at Pearce Ferry or South Cove.

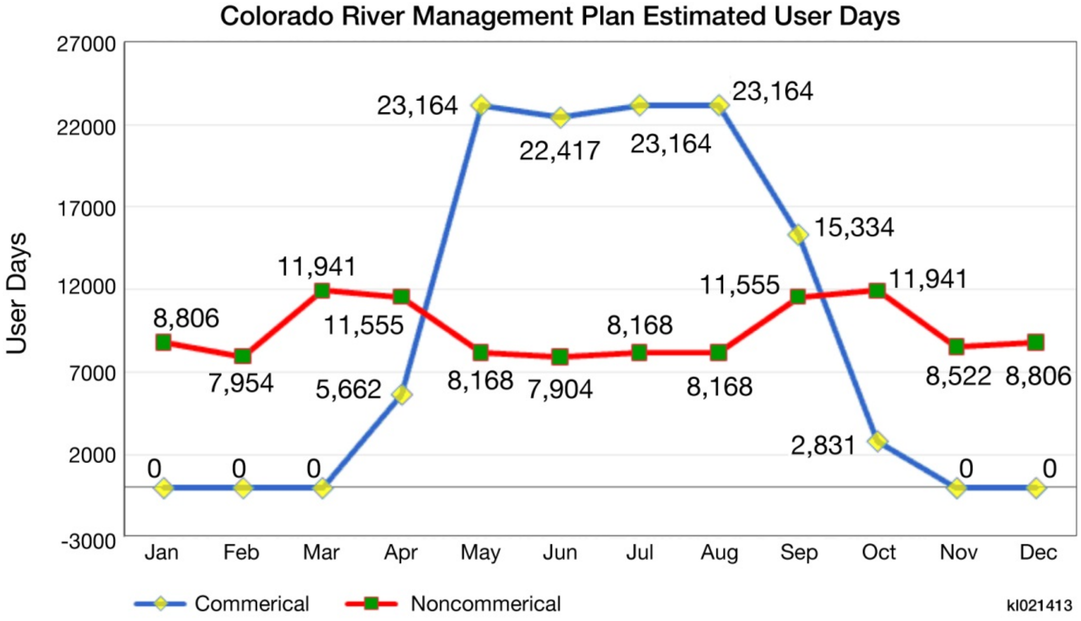

FIGURE 3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month (Source: Reclamation 2011b)

The Lower Gorge of the Grand Canyon is defined as the 51-mi section of river below Diamond Creek (RM 226) to Pearce Ferry (RM 280). Recreational use of the Lower Gorge is described in the CRMP and is managed by the NPS and the Hualapai Tribe, whose reservation is on the south side of the river (located approximately between RM 164.5 and RM 273).

Types and levels of recreational use in the Lower Gorge vary greatly from those above Diamond Creek, primarily due to road and boat access to the river by way of the Hualapai Reservation at Diamond Creek and to the influence of Lake Mead. In addition to river trips that launch from Lees Ferry and continue into the Lower Gorge, the NPS permits noncommercial (private) and educational trips launching from Diamond Creek. Also, the Hualapai Tribe operates its own river program that provides commercial trips beginning at Diamond Creek and other sites on Tribal lands.

Most trips spend fewer than three nights total in the Lower Gorge, although it is possible to spend more if boaters are interested in reservoir travel or off-river hiking. Backcountry permits are required to camp off the river in GCNP, and Hualapai Tribal permits are required for activities on the reservation, including hiking, camping, and conducting research.

3.10.2.1 Campsites in Grand Canyon National Park

River-accessed campsites within GCNP are a memorable aspect of any recreational experience along the river. The number of available campsites and the amount of campsite area at any particular time are affected by river flow (i.e., fewer campsites are available at higher flows, and vice versa). Because of their singular importance in supporting river use, there have been numerous campsite inventories over the years; NPS reported in the CRMP that there are more than 200 regularly used camping beaches in the GCNP planning area. The number and usability of campsites vary from year to year based on several factors, including flow regimes; vegetation changes; erosion from tributary flooding, wind, or recreation use; or closure of sites to protect sensitive resources (NPS 2005a). An updated campsite inventory conducted by the NPS in 2011, identified and classified, by capacity, 235 campsites between Lees Ferry and Diamond Creek.

Preferred beach characteristics for both camping and stops for lunch include a strong preference for shade, larger rather than smaller beaches, and the availability of hiking opportunities (Stewart et al. 2000). "Campable area" is the term used to describe the area of a beach where people set up camp, moor boats, cook, and sleep. The criteria used to define campable area include a smooth substrate, preferably sand, with no more than 8 degrees of slope, and with little or no vegetation (Kaplinski et al. 2010).

Campsites are further classified as being located in either critical or noncritical reaches of the river. A critical reach is any contiguous stretch of river in which the number of available campsites is limited because of geomorphic setting (e.g., narrowed canyon width), high demand for nearby attraction sites, or other logistical factors (e.g., exchange points). Noncritical reaches are those stretches in which campsites are relatively plentiful, resulting in little competition for most sites (Kearsley and Warren 1993).

Campsites vary in size and not all can accommodate the maximum group of 32 described in the CRMP. Researchers, using campsite inventories, have developed three general categories: small camps (1 to 12 people); medium camps (13 to 24 people); and large camps (25 or more people) (NPS 2005a). The results of five campsite inventories conducted between 1973 and 2011 are shown in Figure 3.10-9.

The highest number of camps (particularly large camps) recorded was documented during the inventory conducted immediately following the 1983 flood. By contrast, the 1991 inventory shows 75% fewer large camps than in 1983, while the 2003 inventory shows an even further reduction (NPS 2006b). Compared to 1973, there was about a third as many large camps and a third fewer total camps in 2003 (NPS 2005b). The loss of the large campsites is especially problematic, given the number of large commercial trips during the summer season. The loss increases the potential for groups to camp in close proximity to one another, especially in the critical reaches. This loss led the NPS to reduce group size as identified in the CRMP.

The most important finding regarding campsites in the Grand Canyon is that they are becoming smaller and less abundant. A synthesis of geomorphic data on sandbars below Glen Canyon Dam reported a 25% reduction in the sandbar area within the 87-mi reach from Lees Ferry to Bright Angel Creek between 1984 and 2000 (Schmidt et al. 2004). A study completed in 2010 summarizing detailed topographic campsite monitoring of a sample of 38 sites in GCNP showed that the total amount of high-elevation campsite area above the elevation of 25,000 cfs flow decreased 56% between 1998 and 2006. Figure 3.10-10 shows the described trend for high-elevation campsite area. The primary factors identified in campsite loss

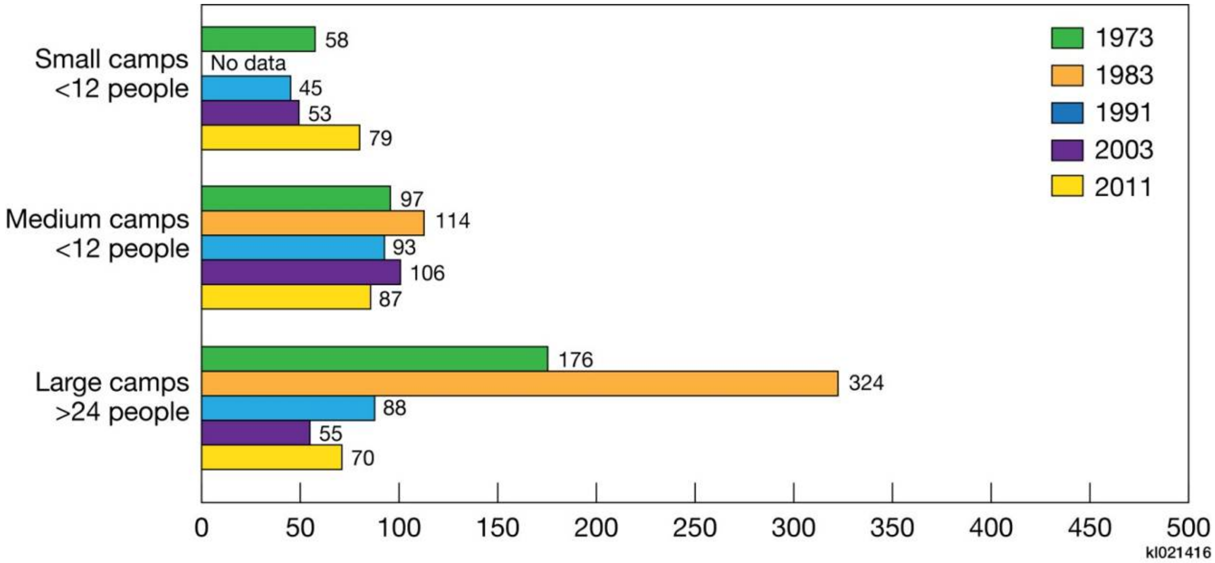

FIGURE 3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach of GCNP (Sources: NPS 2005a; Jalbert 2014)

were riparian vegetation growth and sandbar erosion. These losses happened in spite of a temporary increase of 29% in campsite area between the inventories in 2003 and 2005 that was related to both the 2000 summer low steady flow experiment and the 2004 HFE (Kaplinski et al. 2010). The diminishing availability of campable area, particularly in some of the narrower reaches of the river corridor, is an important issue for national park managers and recreational river runners.

The 2010 Kaplinski et al. study agreed with the findings of Kearsley and Warren (1993) that campsite area in critical reaches decreased primarily due to erosion, and in noncritical reaches, due to increased vegetative cover. Figure 3.10-11 plots the loss of high-elevation campsite area in critical and non-critical reaches.

Over the long term, eddy-sandbar size can only be increased if (1) adequate sediments are available for deposition, (2) high-flow deposition is substantial, (3) high flows occur frequently, and (4) erosion that occurs between high flows is less than the deposition. Thus, the net effect of high flows in building eddy sandbars results from the magnitude and the frequency of high flows and the deposition they cause. Erosion ensues rapidly after each high flow, and the rate of erosion declines thereafter but persists. The longer the time period between HFEs, the more erosion occurs (Melis 2011).

High flows similar in magnitude to those that occurred during the HFEs of 1996, 2004, 2008, 2012, 2013, and 2014 effectively mobilize accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild eddy sandbars in Marble and Grand Canyons. Grams et al. (2010) reported that more erosion occurs when total flow is large (excluding HFEs). Fluctuating flows under normal dam operations between HFEs can erode sandbars and campsites.

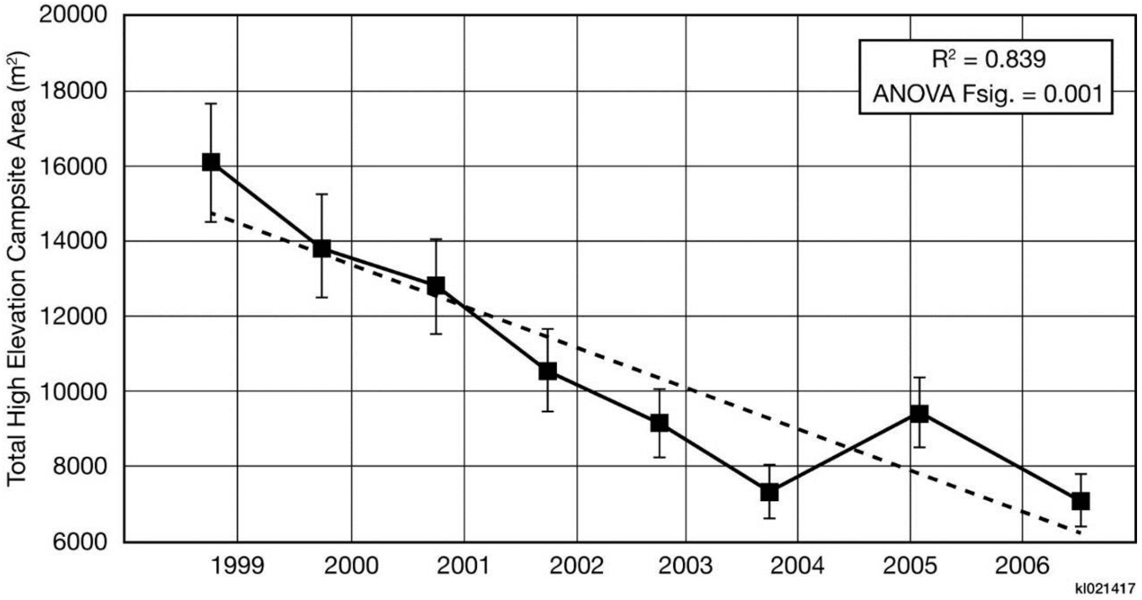

FIGURE 3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and 2006 (with 10% uncertainty bands; the dashed line shows the linear regression fit) (Source: Kaplinski et al. 2010)

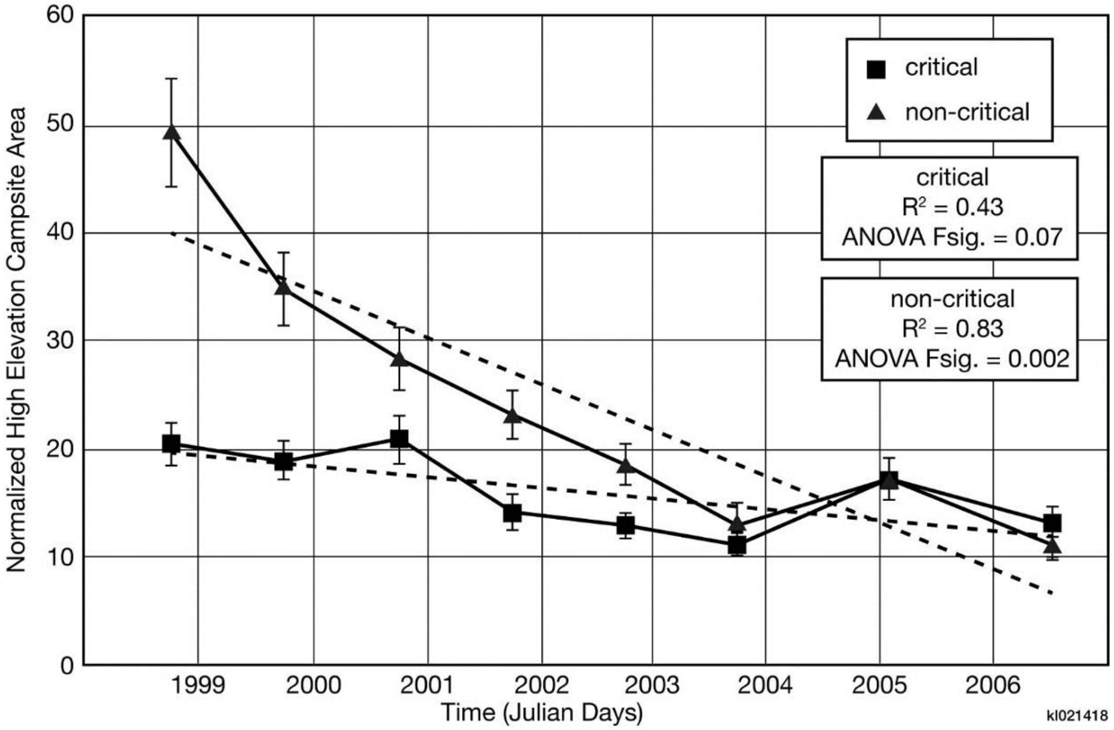

FIGURE 3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between 1998 and 2006 (with 10% uncertainty bands; the dashed lines show the linear regression fit) (Source: Kaplinski et al. 2010)

3.10.2.2 River Flow and Fluctuation

The effect of river flows on recreation in the Grand Canyon has been the subject of studies on the Colorado River for many years that have utilized information from river guides and river trip participants to understand what attributes of river trips are important and how they can be affected by variable river flows (Bishop et al. 1987; Hall and Shelby 2000; Shelby et al. 1992; Stewart et al. 2000; Roberts and Bieri 2001; Ralston 2011). The operation of Glen Canyon Dam commenced in 1963, and the flow regime of the river was first modified in 1991 to address issues that were affecting downstream resources (Reclamation 1995). Principal among these changes was a change in the maximum level of daily river fluctuations from 30,500 cfs to 5,000 cfs, 6,000 cfs, or 8,000 cfs, depending on the scheduled monthly release volumes.

Participants on Grand Canyon river trips have consistently identified several flow-related attributes as being important to their overall trip satisfaction; these include the presence of large rapids, being the only camping group at a beach, and having large beaches for camping (Bishop et al. 1987; Stewart et al. 2000). Large rapids are a function of higher flows. Bishop et al. (1987) found a strong preference among boaters for flows in the range of 25,000–35,000 cfs, a flow range that has been less common since 1996. Flows in this range provided the further benefit that passengers were less likely to be required to walk around rapids. Conversely, higher flows were identified as a potential contributor to crowding at campsites and attractions (Bishop et al. 1987).

The Bishop study (Bishop et al. 1987) further evaluated whitewater boater's preferences with respect to levels of daily flow fluctuations. The study, which was conducted at a time when very large fluctuations were common, identified fluctuations in excess of 10,000 cfs as being noticeable and perceived as less natural to canyon visitors. High fluctuations, ranging from 3,000 to 25,000 cfs/day, were also noted as contributing to issues related to selection of campsites, time allowed at attractions, mooring and tending of boats, transiting major rapids, and trip scheduling. Although such high levels of daily fluctuations are greater than under any LTEMP alternatives, river guides in the Bishop study were also asked to evaluate fluctuation levels that happen to overlap with the alternatives. River guides reported that tolerable fluctuations increased with increasing average daily flow, as shown in Table 3.10-2 (adapted from Bishop et al. 1987), and that the ability to run a whitewater raft trip was particularly sensitive to flow fluctuations when daily flows were low. Based on interviews with guides, the authors concluded that the identified "tolerable" fluctuation ranges were more of a "wish" in the eyes of the guides than specifically "tolerable," as identified on survey forms, and noted that guides stated that predictability in fluctuations is a key factor (Bishop et al. 1987).

Shelby et al. (1992) documented that with daily fluctuations of 9,000–10,000 cfs, boatmen reported problems with boats "left hanging" on beaches by receding water levels. By the time of the Stewart et al. (2000) study, daily fluctuations had been reduced by the MLFF operating regime (capped at 8,000 cfs). Stewart et al. (2000) indicated that "the negative effects of fluctuating flows on recreational use were not substantial problems," but also recorded that "user attitudes and preferences regarding constant flows" had not changed since the 1987 Bishop study.

TABLE 3.10-2 Tolerable Daily Flow Fluctuations Reported by Commercial and Private Trip Leaders

River Flow (cfs)	Tolerable Within-Day Fluctuation (cfs)[a]
5,000–9,000	2,400–3,400
9,000–16,000	3,900–4,800
16,000–32,000	6,400–7,200
32,000 and up	7,900–9,800

[a] Range of mean daily tolerable fluctuations reported by commercial motor guides, commercial oar guides, and private trip leaders who had experienced fluctuations of 15,000 cfs in the Grand Canyon.

Source: Bishop et al. (1987).

It is clear from numerous studies that river flow and management regimes affect whitewater rafting experiences (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000; Ralston 2011). There is general agreement that flows in the 20,000 to 25,000 cfs range are considered to be near optimum for all types of whitewater trips (commercial oar and motor trips and private trips); there is also general agreement that flows of less than about 10,000 cfs are considered to be marginal, while flows of less than 5,000 cfs are considered to be highly unsatisfactory (Bishop et al. 1987; Stewart et al. 2000).

Time Off of the River

A large array of attraction sites, short to long hikes, and campsites are parts of the experience of most river trips through GCNP. There are more than 100 attraction sites available along the river that can be incorporated into a trip, depending on the time available. Most river trips are run on a planned schedule, but longer trips (in number of days) tend to have more flexibility than shorter trips (Roberts and Bieri 2001).

For a river trip of a given distance, river flow rate affects the time available for off-river activities. River flow affects boat speeds, even for motor trips, which affects distance traveled per unit of time. Roberts and Bieri (2001), in their study of the effects of the low steady summer flow experiment of 2000, documented that at a normal flow of 19,000 cfs, river trips spend approximately 7 hr "off river" engaged in activities such as hiking and visiting attraction sites, while during an 8,000-cfs low-flow study, groups spent only about 3.5 hr in these activities. Bishop et al. (1987) recorded that guides indicated that at around 30,000 cfs, additional attraction sites could be included into itineraries. Interestingly, Roberts and Bieri (2001) documented that although substantially less time was available for attraction stops at low flows, the average number of stops stayed near to the norm for average flows. The explanation for this appears to be that some attractions are simply "must see," and a shorter amount of time was allotted for each attraction rather than dropping a site. It was also recorded that some sites become more preferred at lower flows because the activities at those sites require less time to complete. These observations confirmed findings regarding flow impacts on river trips of previous studies (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000).

Studies have also documented that river flows can affect the choice of campsites, how late campsites are reached, how early trips need to break camp, how much or little boatmen are required to row or run motors to keep a trip on schedule, and how many layover days can be taken. Bishop et al. (1987) and Stewart et al. (2000) speculated that the optimum flow level for a Colorado River trip is in the 20,000–25,000 cfs range because of the flexibility that flow offers in accommodating the various competing needs of these trips.

During low-flow periods, in addition to reducing the amount of time at attraction sites, river guides may ask their group to break camp early or they may arrive at camp later in the day than under normal flows. This reduces the amount of camp time, which can also reduce overall trip satisfaction because of the reduced opportunity to explore the areas around camp, to participate in camp activities, or to simply relax.

Having a wilderness experience is one of the top five attributes sought by whitewater boaters (Bishop et al. 1987; Stewart et al. 2000). River flows can have effects on the wilderness experience in at least two ways. The extent that flows limit or reduce the amount of time visitors can spend enjoying the off-river activities affects this aspect of their wilderness experience. In addition, low flows require more motor use during motor-powered river trips (Bishop et al. 1987; Stewart et al. 2000) to maintain schedules. This introduces an additional noise component to the boaters and to the surrounding environment that detracts from the wilderness experience.

Whitewater Boating Experience

One of the attributes desired by participants in river trips is the opportunity to experience big rapids with large waves and a roller-coaster-type ride (Bishop et al. 1987; Stewart et al. 2000). The condition of rapids is related to the flow, with low levels tending to reduce the size of the rapids and the quality of the ride, while high flows tend to wash out smaller rapids. The perception of the quality of rapids is important to an individual's river experience; most related studies were conducted prior to implementation of MLFF and generally identify flow levels of 20,000 to 25,000 cfs as being the optimum "ride" for most participants (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000). Walking around rapids has been identified as one of the attributes that negatively affects the perception of river trips (Bishop et al. 1987; Stewart et al. 2000). Under reduced normal high-flow levels, having participants walk around rapids now is more likely to be related to lower flows.

Availability of Campsites

Higher flows result in reduced campsite area, which can lead to campsites being pushed into more sensitive riparian and old high-water zones. They can also result in more competition for campsites, especially in the critical reaches. Reduced campsite availability can further lead to camps being located more closely together, adversely affecting a sense of solitude and the wilderness experience. In addition, higher flow fluctuations, such as those greater than an 8,000-cfs daily range, affect the ability to both moor boats with less need to attend to them during the night and to access campsites from the river level (Bishop et al. 1987). Current fluctuation levels under MLFF have reduced but not eliminated this issue compared to previous operations (Stewart et al. 2000).

3.10.2.3 Hualapai Tribe Recreation Program

The Hualapai Tribe has implemented a comprehensive recreation services program utilizing Tribal lands that border the Colorado River in the Grand Canyon to generate income for the Tribe. The Tribe, through its Grand Canyon Resort Corporation, manages several businesses that provide recreation services, including a river rafting company. Hualapai River Runners (HRRs) is the only Tribally owned and operated river rafting company on the river. HRR offers commercial motorized day trips from the Diamond Creek and Quartermaster areas on motorized 22-ft pontoon boats. Under a Memorandum of Understanding between the Hualapai Tribe and the NPS, HRR trips are subject to operational standards required of all NPS river concessionaires.

HRR currently offers two types of river trips: (1) short 15-minute boat rides above and below the Quartermaster area (RM 260); this services people who have purchased a tour package that generally originates in Las Vegas, in which passengers are ferried to the launch site by helicopter; and (2) 1-day whitewater raft trips that put in at Diamond Creek and take out at Pearce Ferry. Both types of trips also occur during HFEs (Havatone 2013).

The Tribe authorizes the use of helicopter landing pads (on Reservation lands) both above and below Diamond Creek. The pad near Whitmore (RM 187) is used to exchange passengers from commercial river trips. The helicopter pads at RM 261 are used for day trips that do not involve on-river activities. Helicopter pads at RM 262 and RM 263 are leased to helicopter companies serving HRR river trips, pontoon trips, and trips not involving on-river activities. Noncommercial river rafting passengers do not exchange at these pads.

The landing at Diamond Creek is a major access point to the river and is a prime take-out location for NPS-permitted river trips originating at Lees Ferry. Approximately 85% of noncommercial river rafting trips and a large percentage of commercial trips end at Diamond Creek (NPS 2006b). Diamond Creek is also the starting point for Hualapai Tribe commercial trips through the lower Grand Canyon and for a few noncommercial trips. The Hualapai Tribe maintains the Diamond Creek road and charges a fee for tourists and river runners entering or exiting the river via this road.

The Hualapai Tribe has articulated concerns over the operation of Glen Canyon Dam generally and the effects of HFEs specifically (Havatone 2013). This is addressed in Section 4.10.2.7.

3.10.3 Recreation Use on Lake Mead and Lake Powell

Both Lake Mead and Lake Powell are major destinations for boaters, fishermen, and campers. Drought in the Southwest has been having a major impact on both reservoirs since 2000 and water levels are continuing to decline.

3.10.3.1 Lake Mead National Recreation Area

Lake Mead resulted from the construction of Hoover Dam (once known as Boulder Dam) in 1932. It is the largest reservoir in the United States and at an elevation of 1,221.4 ft AMSL—the elevation of the top of the spillway gates—the reservoir covers 158,500 ac at an elevation of 1221.4 ft. The reservoir extends approximately 110 mi upstream toward the Grand Canyon and about 35 mi up the Virgin River. The elevation of Lake Mead on March 1, 2014, was 1107.74 ft AMSL (Reclamation 2014a). On average, visitors at Lake Mead total about 6 million annually.

Because of the ongoing drought conditions affecting operations at LMNRA, in October 2005, NPS completed a GMP Amendment for Low Water Conditions and a FONSI (NPS 2005b) that identified the strategy for low-water operations. This amendment articulated the intent to maintain boat-launch capacities established in the original GMP of 1986 and a subsequent amendment in 2003, by either extending or relocating existing launch ramps and marinas to be functional down to an elevation of 1,050-ft AMSL. This amendment reflects the current management direction for low-water operations, and it assumes that NPS and concessionaires will continue to modify launching and marina facilities as necessary and possible, given time and budget to continue providing visitor services.

3.10.3.2 Lake Powell, Glen Canyon National Recreation Area

Reclamation completed construction of Glen Canyon Dam in 1963; Lake Powell, which was created by the dam, is the second largest reservoir in the United States. The total capacity of the reservoir is 27 million ac-ft, and it stretches for 186 mi. At full-pool elevation, 3,700 ft, the reservoir has a surface area of 161,390 ac (NPS 2014e). Lake Powell is subject to the same regional drought conditions as Lake Mead, and the elevation of Lake Powell on March 1, 2014, was 3,575.59 ft AMSL (Reclamation 2014a). Annual visitation varies and has been approximately 2 million visitors annually over the past 10 years.

3.10.4 Park Operations and Management

Related to recreation in GCNRA and GCNP is the level of park staffing needed to support recreation and resource protection. The level of staffing affects the ability of the park units to provide appropriate park infrastructure and services to support river and backcountry operations and address visitor experience, and the administrative use of the Colorado River within GCNRA and GCNP. Issues related to park management and operations were raised in public and internal scoping. Some of these issues have been addressed at GCNP by other management documents such as the CRMP (NPS 2006b) and the GCNP General Management Plan (NPS 1995). However, some issues specific to Glen Canyon Dam operations are appropriate for considering within the scope of this EIS. Changes in releases from Glen Canyon Dam may affect the number of personnel, level of funding, and staff time needed to adequately maintain park resources. For example, HFEs require increased staffing resources to notify boaters in Glen and Grand Canyons of high flow releases. In addition, NPS management related to changes in dam operations includes planning, coordination with other agencies, concessionaires, and stakeholders, as well as resource monitoring and visitor safety. Park management and operations may also be affected by non-flow actions.

The Superintendent of each park is ultimately responsible for park management and operations. In 2014, GCNP employed 512 employees (of which 313 are permanent) to manage operations, including visitor services and facilities, resource management and preservation, planning and environmental compliance, emergency medical services, law enforcement, search and rescue operations, fire operations, air operations, facilities management and maintenance, and administrative functions. Similarly, GCNRA employed 214 employees to manage areas including Lake Powell, surrounding lands, and the 15-mi stretch of Glen Canyon below the dam. These resources include a historic district, a campground, and designated campsites along the river with bathrooms and fire pits.

Park divisions with river-related responsibilities include facilities management, visitor and resource protection (permits, inner canyon and river rangers, emergency medical services, and search and rescue operations), concessions management (contracts, commercial use authorizations), interpretation and resource education (signage, information, and interpretation), science and resource management (resource protection, inventory, monitoring, research, and research permitting), and the Office of Planning and Compliance (environmental analysis). River recreational and administrative use is currently managed in accordance with the CRMP (NPS 2006b), the GCNP General Management Plan (NPS 1995), the GCNRA General Management Plan (NPS 1979), and applicable NPS laws, policies, and regulations.

3.11 WILDERNESS

There is proposed wilderness in GCNRA and GCNP that is managed as wilderness pursuant to NPS policy as discussed below. The wilderness proposals within GCNRA and GCNP do not address the Glen Canyon Dam or dam operations. Nothing in this EIS modifies the wilderness proposals in any manner.

This section is included in the EIS primarily to address activities conducted or permitted by the NPS (including research as part of the Glen Canyon Dam Adaptive Management Program [GCDAMP]). Approximately 94% of GCNP, or 1,143,918 ac, qualifies as Wilderness as described in the 1964 Wilderness Act and NPS *Management Policies 2006* (NPS 2006d). Grand Canyon Wilderness complements other Designated and Proposed Wilderness Areas north of the Grand Canyon on other NPS, Bureau of Land Management (BLM), and U.S. Forest Service (USFS) lands. Approximately 51% of Glen Canyon, or 588,855 ac, was proposed for wilderness designation. This includes 6,180 ac in the Paria unit of the Glen Canyon proposed wilderness.

3.11.1 Law and Policy

The Wilderness Act of 1964 required the Secretaries of Agriculture and the Interior to evaluate land under their jurisdiction for possible wilderness classification. Section 4 of the Wilderness Act describes authorized uses of wilderness areas; subsection 4(a) declares, with specific legislative references, that the Wilderness Act shall be supplemental to the purposes for which the national forests, parks, and refuges have been established. Subsection 4(b) states, in part:

> Except as otherwise provided in this Act, each agency administering any area designated as wilderness shall be responsible for preserving the wilderness character of the area and shall so administer such area for such other purposes for which it may have been established as also to preserve its wilderness character. Thus, except for specified provisions in the legislation, wilderness areas shall be devoted to recreational, scenic, scientific, educational, conservation, and historical uses.

Subsection 4(c) prohibits certain uses (unless specifically provided elsewhere in the Act) that are inconsistent with wilderness preservation. With the exception of the minimum actions needed for administrative duties and emergency health and safety procedures, the Act prohibits temporary roads, motor vehicle use, motorized equipment or motorboats, landing of aircraft, mechanical transport, structures, and installations.

Section 4 also addresses special provisions for certain wilderness uses. Subsection 4(d)(1) states, in part:

> Within wilderness areas designated by this Act the use of aircraft or motorboats, where these uses have already become established, may be permitted to continue. These uses are subject to such restrictions as the administering federal official deems desirable. Subsection 4(d)(5) permits the performance of commercial services within wilderness to the extent necessary for activities which are proper for realizing the recreational or other wilderness purposes of this act.

In addition, NPS Management Policies 2006 (NPS 2006d) includes the following:

> The National Park Service will take no action that would diminish the wilderness suitability of an area possessing wilderness characteristics until the legislative process of wilderness designation has been completed. Until that time, management decision pertaining to lands qualifying as wilderness will be made in expectation of eventual wilderness designation. This policy also applies to potential wilderness, requiring it to be managed as wilderness to the extent that existing non-conforming conditions allow. The National Park Service will seek to

> remove from potential wilderness the temporary, non-conforming conditions that preclude wilderness designation.

NPS will manage proposed wilderness in GCNP and GCNRA in accordance with NPS Management Policies and the Wilderness Act of 1964. This area includes the 277-mi section of the Colorado River within the boundaries of GCNP and portions of the Lees Ferry District, including a 15-mi section of the river downstream of the dam in GCNRA. The Final EIS for the GCNP Colorado River Management Plan (NPS 2005a) clarifies that recreational motorized use does not preclude possible wilderness designation because such use is a temporary or transient disturbance of wilderness values and does not permanently impact wilderness resources. The 2006 CRMP established a 6.5-month no-motor season to enhance opportunities for a wilderness experience (NPS 2006b).

NPS policy requires that its wilderness management decisions be consistent with a minimum requirement concept that evaluates the potential disruptions of wilderness character and resources. The minimum requirement concept applies to all administrative activities, including research and monitoring. Research trips of NPS, USGS, and other agencies are subject to the minimum requirement policy.

3.11.2 Defining Wilderness Character

According to GCNP's GMP, areas proposed for wilderness offer visitors opportunities for solitude and primitive recreation. An important provision in the GMP states:

> The management of these areas should preserve the wilderness values and character. Non-wilderness undeveloped areas should continue to serve primarily as primitive thresholds to wilderness. Visitors traveling through the canyon on the Colorado River should have the opportunity for a variety of personal outdoor experiences, ranging from solitary to social. Visitors should be able to continue to experience the river corridor with as little influence from the modern world as possible. The river experience should help visitors to intimately relate to the majesty of the canyon (NPS 1995).
>
> Subsection 2(c) of the Wilderness Act defines wilderness as follows:
>
> A wilderness, in contrast with those areas where man and his works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain.

The same subsection 2(c) further defines wilderness as having the following characteristics:

- Undeveloped land retaining its primeval character in influence without permanent improvements or human habitation

- Generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable
- Has outstanding opportunities for solitude or primitive and unconfined type of recreation
- May contain ecological, geological, scientific, educational, scenic, or historical value

This last quality, recognizing ecological, geological, scientific, educational, scenic, or historical value, is of particular importance when describing the Colorado River and the greater Grand Canyon. To the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, Southern Paiute Tribes, and other American Indian Tribes, the canyon and river represent significant cultural, educational, and historical places that are central to their cultural identity.

Wilderness character is defined in NPS Wilderness Stewardship Reference Manual 41 as, "The combination of biophysical, experiential, and symbolic ideals that distinguishes Wilderness from other lands. The five qualities of Wilderness Character are Untrammeled, Undeveloped, Natural, Solitude or a Primitive and Unconfined Type of Recreation, and Other Features of Value."

All designated wilderness areas, regardless of size, location, or any other feature, are unified by the statutory definition. These four qualities of wilderness are as follows:

1. **Untrammeled**—wilderness is essentially unhindered and free from modern human control or manipulation. This quality pertains to actions that manipulate or control ecological systems.
2. **Natural**—wilderness ecological systems are substantially free from the effects of modern civilization. In the context of managing visitor use on the Colorado River, this quality pertains to the intended and unintended human-caused effects on natural and cultural resources conditions.
3. **Undeveloped**—wilderness is essentially without permanent improvements or modern human occupation. This quality pertains to the presence and development level of trails, campsites, structures, and facilities within the river corridor and areas visited by river users.
4. **Outstanding opportunities for solitude or a primitive and unconfined type of recreation**—wilderness provides outstanding opportunities for people to experience solitude or primitive and unconfined recreation, including the values of inspiration and physical and mental challenge. This quality pertains to visitor opportunities to experience a primitive setting that may include solitude and adventure.

The fifth quality articulated in the definition of wilderness character above is defined as follows:

5. **Other features of scientific, educational, scenic, or historical value**—attributes not required of or found in every wilderness that reflect a wilderness' specific wilderness character, and is based on the Wilderness Act's Section 2(c) that states a wilderness "may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value."

This component captures important wilderness elements not covered in the other four Wilderness Character qualities such as cultural or paleontological resources. The three NPS units within the project area protect important cultural histories, significant traditional cultural resources, and extensive archeological records important to preserving the Wilderness Character of the area. The relationship between these qualities and impacts related to Glen Canyon Dam operations are important components of these analyses and will be further discussed in Chapter 4.

3.12 VISUAL RESOURCES

Visual resources refer to all objects (man-made and natural, moving and stationary) and features (e.g., landforms, night skies, and water bodies) that are visible on a landscape. These resources add to or detract from the scenic quality of the landscape; that is, the visual appeal of the landscape. Visual impacts can be defined as changes to scenic attributes of the landscape brought about by the introduction of visual contrasts and the associated changes in the human visual experience of the landscape. A visual impact can be perceived by an individual or group as either positive or negative, depending on a variety of factors relating to personal circumstances (e.g., personal experience, aesthetic sensitivity, or the activity in which the viewer is engaged) or to viewing circumstances (e.g., viewing distance, time of day, or weather/seasonal conditions).

Visual resources are not only important to visitor enjoyment of GCNRA, GCNP, and LMNRA, they are important to American Indian communities who once resided in and/or visit the area for subsistence or ceremonial purposes. Conservation of visual resources is part of the GCPA of 1992 and an important component of the federal management activities for these areas. Scenic resources found within GCNRA, GCNP, and LMNRA and on Hualapai and Navajo reservations include colorful and unique geological formations; complex geology; sleek canyon walls; towering cliffs, buttes, and mesas; rivers, lakes, and streams; barren deserts; and unique prehistoric and historic cultural sites. The scenic resources of these areas are experienced in a number of ways. The Canyons have a significant place in the traditional cosmology of the indigenous communities of the Southwest. American Indian communities may visually experience the Canyons quite differently than recreational users who experience the Canyons not only during recreational activities but also while gathering natural resources or performing religious ceremonies. Water-based recreational activities such as boating, kayaking, swimming, and fishing allow individuals to view the varied landscapes of the Colorado River, Grand and

Glen Canyons, Lake Powell, and Lake Mead from almost anywhere on the water. Stewart et al. (2000) found that the more valued aspects of a river rafting trip include simply being in a natural setting, having the opportunity to stop in scenic places, and being able to view flora, fauna, and geology. Terrestrial activities such as hiking and camping along the shores of Lake Powell, Lake Mead, and the Colorado River offer spectacular views, as do designated scenic overlooks accessible via boat, car, or hiking trail. For many Tribes, trails that enter the Canyons are sacred and the scenic setting along these trails plays an important part in the travel and ceremonial experience.

Vegetation also plays an important role in the scenic experience along the Colorado River and in Glen Canyon. Vegetation increases the visual interest of many places by adding variety in color and texture and is also a visual cue for Tribes in determining the health of the ecosystem. For example, sandbars and marshes along the river may contain stands of native vegetation which are important for many Tribal communities. For recreational visitors, native vegetation adds variety in color, texture, and form in contrast to the river and surrounding canyon walls, as well as affording the viewer a chance to see native plant life. Stands of nonnative tamarisk that occur along the river are visual evidence of a nonnative plant species. In addition, nonnative plants may have a different texture than native vegetation, and therefore create visual contrast. A full discussion of plant communities can be found in Section 3.6.

Hanging gardens are a unique feature formed when springwater flows through cracks in sandstone and seeps out through canyon walls, allowing plants to grow vertically along the walls and on the canyon floor below (Woods et al. 2001). Where visible to visitors, hanging gardens add visual interest through color and texture contrasts with the surrounding bare rock, and they are visually important to Tribes for various reasons.

3.12.1 Glen Canyon National Recreation Area

The deep, 15-mi long, narrow gorge below the dam provides a glimpse of the high canyon walls, ancient rock art, and a vestige of the riparian and beach terrace environments that were a daily experience for American Indians and first recorded in John Wesley Powell's Colorado River expedition in 1869, providing stark contrast to the impounded canyons of Lake Powell. Portions of this stretch of river are classified as either Class I or Class II scenic areas and are managed as a Natural Zone (NPS 1979). At GCNRA, the Natural Zone is managed for its outstanding scenic resources and relatively undisturbed areas that remain isolated and remote from human activities. Class I scenic areas have outstanding scenic qualities such as "intricately carved landscapes, unique canyons, and unique geological structures," and Class II scenic areas have a "single property of superior quality or a diversity of form and color." This stretch of river also includes unique historic and prehistoric sites such as Lees Ferry and Lonely Dell Ranch (NRHP 1997) and the 9-mi Descending Sheep Panel, as well as features such as Paria Beach, the Glen Canyon Dam, and the popular hiking and photographic destination Horseshoe Bend, an "awe-inspiring bend in the Colorado River" where the rocks and river change color throughout the day (NPS 2007; Hughes 2014b). Examples of these resources are shown in Figures 3.12-1 and 3.12–2. Downstream of the dam, HFEs and fluctuations in daily

FIGURE 3.12-1 Glen Canyon Viewed from the Colorado River

FIGURE 3.12-2 Horseshoe Bend (Photo credit: Massimo Tava)

flow can alter the size and shape of sandbars and scour and erode vegetation along the banks of the river, causing changes in landscape forms, lines, colors, and textures.

3.12.2 Grand Canyon and the Colorado River

Conserving the Grand Canyon's scenic resources is an important part of GCNP management goals. The Colorado River falls within GCNP's Natural Zone which is managed to conserve natural resources and ecological processes while providing for their use by the public, using management techniques that have no adverse effect on scenic quality and natural processes (NPS 1995). Segments of the Colorado River and its tributaries are eligible for Wild and Scenic River status, although an official determination has not yet been made (NPS 1995). The park's Foundation Statement identified the scenic landscape as a primary interpretive theme and further identified "Scenic Qualities and Values" as components of the fundamental resource "Preserving Visitor Experiences in an Outstanding Natural Landscape" (NPS 2010a). In recognition of its outstanding visual landscapes and its biological and cultural significance, the Grand Canyon was designated as a World Heritage Site in 1979 (UNESCO 2012).

The Colorado River flows for 277 mi through the Grand Canyon. As it flows through the canyon, the river offers spectacular views of complex geology, hardened lava flows, waterfalls, sandy beaches, sheer cliffs, towering buttes, hidden caves, and side canyons (NPS 2013l; Belknap and Belknap-Evans 2012).

The Colorado River can be seen from many viewpoints accessible along the rims and inner canyon hiking trails. These vantage points offer spectacular panoramas of the Colorado River as it winds through the Grand Canyon. Of the nearly 5 million annual visitors to the Grand Canyon, most view the Colorado River from the rim. Scenic overlooks on the South Rim along the Hermit Rim Road and Arizona State Route 64 include Mohave, Pima, Hopi, Moran, Lipan, and Desert Viewpoints. North Rim overlooks along the scenic road include Point Imperial, Walhalla Overlook, and Cape Royal. The view from the Toroweap Point overlook is one of the most photographed views of the Colorado River (Belknap and Belknap-Evans 2012; Kaiser 2010; Martin 2010; NPS 2015d; Balsom 2014).

A river trip through the Grand Canyon provides spectacular views of scenic resources along the Colorado River (Figures 3.12-3 and 3.12-4). These include unique cultural sites such as the granaries at Nankoweap (Figure 3.12-4) and Phantom Ranch; exceptionally scenic side canyons and tributaries such as the confluence with the Little Colorado River, Havasu Canyon (Figure 3.12-5), Deer Creek Narrows, Blacktail Canyon, Kanab Creek, and Diamond Creek; and distinctive and colorful geological features caverns, alcoves, grottos, and chasms that range in color from brown, reddish-brown, and orange to light tans and yellows to grays and purples. Redwall Cavern, Elves' Chasm, Vasey's Paradise (Figure 3.12-6), Silver Grotto, Whitmore Wash, Unkar Delta, and Lava Falls are among the most popular scenic geological formations along the river (Belknap and Belknap-Evans 2012; Kaiser 2010; Martin and Whitis 2008).

Campsites are located along the river's edge on sandy beaches or on ledges and alcoves above the high-water mark. Campsites offer the viewer a chance to see native plant and animal

FIGURE 3.12-3 Typical View of the Colorado River and Grand Canyon Afforded Recreationists on a River Trip

FIGURE 3.12-4 Colorado River and Granaries at Nankoweap (Photo credit: Mark Lellouch, NPS)

FIGURE 3.12-5 Entrance to Havasu Canyon (Photo credit: Erin Whitaker, NPS)

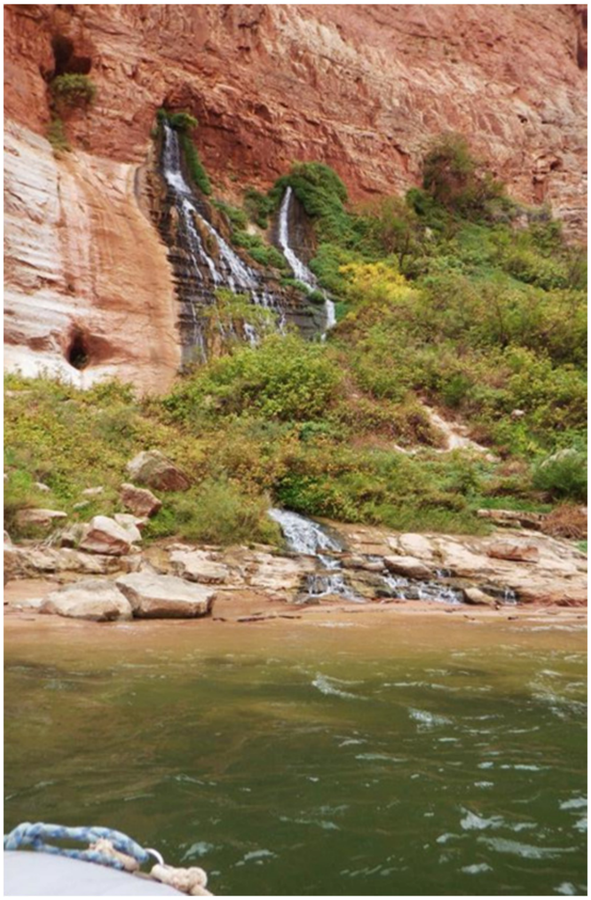

FIGURE 3.12-6 Vasey's Paradise

life, in addition to offering views of the Colorado River and surrounding landscape. Many trails are accessible only from these campsites and lead visitors to scenic vantage points of the Grand Canyon and Colorado River (NPS 2010a). See Section 3.11 for a more detailed description of campsites.

Dam operations may contribute to effects on visual resources along the Colorado River in the Grand Canyon. Prior to construction of Glen Canyon Dam, the banks of the Colorado River consisted primarily of open sandy beaches and bare talus slopes with native riparian vegetation established above the elevation of annual scouring flows within the Grand Canyon. These beaches and vegetation were depleted and replenished as the Colorado River picked up and deposited debris during seasonal floods (USGS 2007; NPS 2013i). Currently, the size and shape of beaches along the river can change frequently with changing river flows and water levels. Much of the sediment that would otherwise move through the canyon is now trapped behind the dam, and regular seasonal flooding does not occur. Because of this, the river lacks the sediment it needs to build up beaches and sandbars, and the beaches sometimes disappear altogether (NPS 2013i). In addition, beaches that are more stable are no longer scoured by occasional flooding, which allows vegetation, including nonnative species such as tamarisk, to take hold and spread (GCMRC 2011). The changes to the size and shape of beaches and the amount and types of riparian vegetation create visual contrasts that may affect visitors' scenic experiences.

Prior to construction of Glen Canyon Dam, the Colorado River carried such a large sediment load that it ran a reddish-brown color throughout the canyon. Now, the river downstream from the dam is relatively clear and green in color. During high releases or after large tributary inputs of suspended sediment, water becomes much more reddish-brown; this effect is ephemeral, however, and water quickly returns to a bluish-green color (NPS 2013g; USGS 2007). Calcium carbonate banding resulting from deposition of minerals at the water edge is also visible in some areas along the Colorado River, typically where the river bank consists of bare rock walls, rocky slopes, or boulders. The changes in water color, depth, and texture may affect the scenic experience of river runners.

3.12.3 Lake Mead National Recreation Area

LMNRA is managed for general recreational purposes to enhance visitor use, while recognizing the importance of and preserving its scenic, historic, and scientific resources (NPS 2002c). Pearce Ferry, located in the northeastern end of the park, serves as the boundary between the Grand Canyon and Lake Mead and marks the final destination for rafting trips down the lower Grand Canyon area. This area is mostly managed as a rural natural setting, where man-made features are present, but natural landscape is predominant.

Scenic resources within LMNRA include Lake Mead itself and the low, rocky, volcanic hills; steep canyons; and colorful rock formations that surround the reservoir. The surrounding landscape ranges in color from light tans and yellows to bright reds and browns, and contrasts sharply with the striking blue waters of Lake Mead and the bluish-green waters of the Colorado River.

Sediment deltas resulting from sediment transported through the Grand Canyon have built up in the headwaters of Lake Mead near Peace Ferry (Reclamation 2007a) and Iceberg Canyon (NPS 2015c), areas that are considered rural natural settings. Sediment deltas contribute to changes in form, line, color, and texture that can affect the overall scenic experience of water recreationists and may interfere with management objectives that include the protection of natural-appearing landscapes and pristine views.

3.13 HYDROPOWER

This section describes power operations and power marketing as they relate to Glen Canyon Dam and the Glen Canyon Powerplant. A description of the seven-state socioeconomic environment in which power from the powerplant is marketed is provided in Section 3.14.

The operation of Glen Canyon Dam and Powerplant directly and indirectly influences the downstream physical environment and aquatic and riparian habitats. For example, the frequency and magnitude of daily fluctuations (for the purposes of following electrical loads and maximizing the value of hydropower) directly affect sediment transport and deposition downstream, directly or indirectly affect aquatic and riparian habitats, affect the recreational environment (beach areas) and use patterns, and indirectly affect air emissions and water consumption for the region.

Power generation from the dam also financially affects the U.S. Department of Energy's (DOE's) Western Area Power Administration (WAPA) customers. When generation from the powerplant is significantly reduced or not timed to match hourly load patterns and WAPA is unable to fulfill its contractual obligations from existing Salt Lake City Area Integrated Projects (SLCA/IP) resources, WAPA must purchase power from other market sources to meet any contractual obligations. Those alternate sources are typically derived from power-generation sources fueled by natural gas, coal, oil, nuclear, and to a much lesser degree, solar and wind. Each power-generation source has its own characteristic air emissions, water consumption, and economic impacts. In the event customer contractual allocations are reduced, the customers would be required to replace that capacity and energy from an alternate source through a purchase or build-out of new generation.

All of the potential impacts noted above are influenced by hourly, daily, monthly, and annual patterns and variations in how water is released from Glen Canyon Dam to produce electricity, and how those releases are typically timed to enhance the value of power generation. Ramp rates (i.e., the rate, in cfs/hr, at which dam releases rise or fall, referred to hereafter as up-ramp rates and down-ramp rates, respectively), flow rates (in cfs), maximum and minimum daily flows (cfs), daily/monthly release volumes (ac-ft), and reservoir elevation (head) are all factors that influence the extent of impacts of dam operations on electrical power customers, downstream environmental resources, Tribal cultural sites, recreational users, and WAPA's repayment obligations and the ability to fund CRSP operations and important environmental programs in the Upper Basin.

3.13.1 Power Operations

Power operations are the physical operations of a large electrical power system, including hydropower generation, and control (operational flexibility, scheduling, load/generation following, regulation, reserves, and transmission).

3.13.1.1 Hydropower Generation

The Glen Canyon Powerplant has eight generators with a maximum combined capacity of 1,320 MW when the reservoir elevation is 3,700 ft AMSL. The maximum combined discharge (water release) capacity of the eight turbines is approximately 31,500 cfs. Under the current operating regime of MLFF adopted in the 1996 ROD (Reclamation 1996), the maximum release is limited to 25,000 cfs, except in extreme hydrologic or emergency conditions or under approved experimental actions (i.e., HFE protocol). This maximum release restriction limits Glen Canyon Dam power generation capacity to approximately 1,000 MW at a reservoir level of

3,700 ft AMSL, which is 76% of potential usable capacity without restriction. The generators require a minimum Lake Powell elevation of 3,490 ft AMSL to operate. At this elevation, the maximum capacity of the Glen Canyon Powerplant is reduced to approximately 630 MW. Prior to 1991, annual gross generation ranged from a minimum of 1.1 million MWh to a maximum of 8.8 million MWh, with an average of 4.4 million MWh. With the Interim Flows decision in 1990, generation between 1991 and 1996 ranged between 3.6 million MWh and 5.5 million MWh, averaging 4.1 million MWh, and with the adoption of the current operating regime (MLFF), generation from 1997 to 2015 has ranged between 3.1 million MWh and 6.7 million MWh, with an average of 4.2 million MWh (Reclamation 2014b). Since the implementation of MLFF, between 1997 and 2005, the average annual cost incurred from operational restrictions ranged from $38 million to $50 million (Veselka et al. 2010).

Releases that bypass the generators (such as in the case of HFEs) do not generate power, and therefore have no power system economic value. Turbines are operating at maximum capacity during HFEs, which does generate more power than the normal operations; however, there are marketing challenges due to the short-term nature of this generation during the HFE.

Glen Canyon Dam and Powerplant is the largest facility in the CRSP, which also includes other power facilities (e.g., Aspinall Unit [Blue Mesa, Crystal, and Morrow Point dams] in Colorado, and Flaming Gorge Dam in Utah). The power produced at these facilities, which includes both capacity and energy[11] generated at Glen Canyon Dam and other CRSP facilities, is marketed by WAPA. Net winter and summer energy (adding purchases to the combined powerplant resources and subtracting losses and project use) marketed by WAPA is currently 2,558 and 2,394 GWh, respectively, while net winter and summer capacity (subtracting project-use loads, system losses, control area regulation needs, firm-load reserves, and scheduled-outage-assistance-loads from generating capability) are 1,404 MW and 1,318 MW, respectively. Seasonal variation is due to differences in typical reservoir elevations and project-use loads (Reclamation 1995).

To coordinate electric power rate-setting and marketing efforts and ensure the timely repayment of federal project construction and irrigation assistance debt, the Colorado River Storage, Collbran, and Rio Grande Projects were administratively integrated in 1987 into the Salt Lake City Area Integrated Projects (SLCA/IP), which is part of an interconnected generation and transmission system that includes federal, public, and private power generating facilities (Reclamation 1995).

3.13.1.2 Basin Fund

The Upper Colorado River Basin Fund (Basin Fund) was established under Section 5 of CRSPA. CRSPA "authorized a separate fund in the Treasury of the United States to be known as

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[11] Energy (typically measured in MWh) is electricity generated and/or used over time; capacity (typically measured in MW) is total powerplant generation capability.

the Upper Colorado River Basin Fund [...] for carrying out provisions of this Act other than Section 8." Money appropriated for construction of CRSP facilities, except recreation and fish and wildlife facilities constructed under Section 8, is transferred to the Basin Fund from the General Fund of the Treasury. Revenues derived from operation of the CRSP and participating projects are deposited in the Basin Fund. Most of the revenues come from sales of hydroelectric power and transmission services. The Basin Fund also receives revenues from municipal and industrial water service sales, rents, salinity funds from the Lower Colorado Basin (as a pass-through for the Colorado River Basin Salinity Control Program), and miscellaneous revenues collected in connection with the operation of the CRSP and participating projects. Revenues and appropriated funds are accounted for separately in the Basin Fund.

3.13.1.3 Operational Flexibility

The operational flexibility of hydroelectric power generation allows WAPA to quickly and efficiently increase or decrease generation in response to customer demand, generating unit or transmission line outages (contingency reserves), unscheduled customer deviation from internally scheduled contracted power usage (regulation and load/generation following) within a specific metered load area known as a Balancing Authority (BA),[12] integrated power system requirements, and requests for emergency assistance from interconnected utilities. Under the water release parameters instituted on an interim basis in 1991 and permanently under the 1996 ROD following the completion of the Glen Canyon Environmental Impact Statement (Reclamation 1995), WAPA currently restricts the scheduling of customer contract allocations to 2-day-ahead prescheduling only. Ramping restrictions, imposed under the 1996 ROD operating criteria, do not allow generation at Glen Canyon Dam to adjust sufficiently each hour to match the power customer demand schedules. These ramping restrictions result in increased use of alternate generating resources to meet power customer demand schedules. Operational conditions are complicated by the frequency, season, and time of day any of these events may occur; physical and environmental operating restrictions at other CRSP generating facilities and within the interconnected electric system; and the availability and price of alternative power resources (Reclamation 1995).

Although there is considerable potential for flexibility in Glen Canyon powerplant operations, current operating criteria have placed multiple restrictions on the variability of water released from the dam, thus restricting operations at the powerplant. Prior to 1991, Reclamation operated the dam and powerplant to maintain a minimum release of 3,000 cfs in summer months, and maintained a 1,000-cfs limit minimum flow for the remainder of the year. There were no restrictions on ramp rates, and daily fluctuations were occasionally as high as 28,500 cfs in the summer months and 30,500 cfs for the rest of the year (Poch et al. 2011). Beginning in August 1991, an Interim Flows decision restricted the operation of the dam for environmental reasons, and the Interim Flows decision was used as the basis for operation until February 1997, when the February 1997 operating criteria, based on the 1996 ROD, restricted dam operational

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[12] Note that in this section of the EIS, BA is used as the abbreviation for Balancing Authority. In other sections of the DEIS, BA refers to Biological Assessment.

flexibility. This operating regime, referred to as MLFF, is currently used as the basis of operations at Glen Canyon Dam and requires water release rates to be 8,000 cfs or greater between the hours of 7 a.m. and 7 p.m., and at least 5,000 cfs at night. The criteria also limit ramp rates; the maximum hourly increase (i.e., the up-ramp rate) is 4,000 cfs/hr, and the maximum hourly decrease (i.e., the down-ramp rate) is 1,500 cfs/hr. The 1996 ROD operating criteria also restricted the extent to which releases can fluctuate during a rolling 24-hour period. This change constraint varies between 5,000 cfs/day and 8,000 cfs/day, depending on the monthly volume of water releases. Daily fluctuation is limited to 5,000 cfs in months when less than 600 thousand acre-feet (kaf) is released. The fluctuation limit increases to 6,000 cfs when monthly release volumes are between 600 kaf and 800 kaf. When the monthly water release volume is 800 kaf or higher, the daily allowable fluctuation is 8,000 cfs (Reclamation 1995; Poch et al. 2011). MLFF includes emergency exception criteria.

Under MLFF, the maximum release rate for power generation is limited to 25,000 cfs. Maximum release rate exceptions are allowed if needed to avoid spills or flood releases during high runoff periods or if authorized under approved experimental action (i.e., HFE protocol). Under very wet hydrologic conditions, defined as when the average monthly release rate is greater than 25,000 cfs, the flow rate may be exceeded, but water must be released at a constant rate. Adjustments to MLFF are made to avoid spills, during flood releases, to accommodate experimental releases, and to accommodate electrical emergencies. These adjustments include maximum release rates above 25,000 cfs. Experimental releases may require release rates in excess of the capacity of the powerplant. When this situation occurs, additional water would be released through bypass tubes to achieve the desired high release rate. Bypassing water around the generators produces no energy, which can result in additional purchases of replacement power, and increases the river stage in the tailwater, which reduces elevation, thereby reducing the effective head and power conversion rates for water passing through powerplant turbines (Poch et al. 2011).

3.13.1.4 Scheduling

Power scheduling is the matching of seasonal, daily, and hourly system energy and capacity needs with available generation. At Glen Canyon Dam, power scheduling is affected by the distribution of monthly water release volumes, restrictions in water release patterns (maximum and minimum release limits, allowable daily fluctuation rates, and hourly ramp rates), availability of the eight units in the Glen Canyon Powerplant and other CRSP units (individual units are on a rotating maintenance schedule) in the system, power customer allocations, and peak and off-peak power periods. Weather and runoff forecasts, alternate resource availability, and the market price of electricity also play important roles in how the customers schedule their allocation of CRSP resources (Reclamation 1995).

Scheduling to meet power requirements generally means higher water releases in peak months when the demand for power (load) is higher (December, January, July, and August) and lower water releases when electric power demand is lower.

Prior to 1990, dispatch (the sequence in which SLCA/IP powerplants are utilized to meet the demand for electricity) from powerplants was driven primarily by market prices. A high level of operating flexibility at the SLCA/IP allowed WAPA to purchase energy during off-peak periods to meet customer demand, storing the water for later power generation during on-peak periods when prices were higher. Accordingly, WAPA was able to maximize the economic value of electricity sales from the Glen Canyon Powerplant. Since MLFF operational constraints were imposed on SLCA/IP resources, including those at Glen Canyon Dam, SLCA/IP powerplants have been dispatched independently to meet contractual obligations at the lowest possible cost, with the lowest variable operating costs generally dispatched first, and plants with higher variable operating costs brought online sequentially as electricity demand increases. Hourly differences between loads and resource production are reconciled though market purchases and sales. Within the operational restrictions of MLFF, there are many hourly release patterns and dispatch arrangements that comply with the operating criteria to provide scheduling flexibility to meet power customer demand. However, since the implementation of MLFF, between 1997 and 2005, the average annual cost incurred ranged from $38 million to $50 million, due to operational restrictions (Veselka et al. 2010).

3.13.1.5 Load/Generation Following and Regulation

To ensure interconnected system reliability, WAPA follows mandatory reliability standards enforced by the North American Electric Reliability Corporation (NERC) and the Western Electricity Coordinating Council (WECC). In addition, WAPA follows operational criteria, guidelines, and procedures set in place by the WECC and the contingency Reserve Sharing Group (RSG) applicable to each BA. Each WECC utility is located within such a load control area, and one utility within the BA serves as the BA operator. WAPA is the BA operator for the Western Area Lower Colorado Region (WALC) BA, the Western Area Colorado-Missouri Region (WACM) BA, and the Western Area Upper Great Plains West Region (WAUW) BA, and is responsible for ensuring that each load-serving utility within each BA serves its own internal load while meeting its power and reserve obligations. Operating as a BA, WAPA is the provider of last resort should a load-serving entity not be able to fulfill its obligation to the BA, and it carries all compliance responsibility for the BA function. All CRSP powerplants are within the WACM BA, and the flexibility and load/generation following capability of CRSP hydroelectric powerplants, particularly Glen Canyon Powerplant, are important in meeting NERC/WECC reliability standards and criteria.

Hydropower generation is valuable because it can react instantaneously to changes in load or unanticipated changes in generation resources within the BA. This ability to respond to rapidly changing load conditions is called load and/or generation following regulation. As a BA operator, WAPA utilizes its hydrogeneration resources, and hydropower is typically used to balance instantaneous changes to loads and/or generation within the metered transmission and generation BA system. By comparison, coal- and nuclear-based resources have a very slow response time, and consequently have limited load/generation following regulation capability. Load/generation following regulation capability at Glen Canyon Dam is limited to ± 40 MW and is outside the 1996 ROD operating criteria ramping restrictions.

In general, power demand increases during the daylight hours as residences, commercial establishments, agriculture, and industrial electrical demands increase. Under normal conditions, the system load pattern throughout the region is similar from Monday through Friday, but load often drops considerably on Saturday and Sunday as companies with a heavy commercial or industrial load shut down. System load also varies seasonally with increases in the conditions load in December, January, July, and August, and lower demand for power in the remaining months (Reclamation 1995).

Implementation of the 1996 ROD operating criteria has reduced the ability of power generation at Glen Canyon Dam to follow hourly changes in customer load. Prior to the 1990s, power generation from CRSP powerplants, including Glen Canyon Dam, was driven primarily to meet daily and seasonal power demands. A high level of operating flexibility at these federal facilities allowed power generation to closely follow on- and off-peak electrical loads which made these federal facilities valuable assets in developing the economies of the Western United States. For example, during the 1978 energy crisis, Glen Canyon Dam was operated under an executive order that required federal agencies to exercise their authorities to increase domestic energy production and reduce U.S dependence on foreign oil. Accordingly, WAPA was able to increase the economic value of electricity deliveries to its electrical customers using generation at Glen Canyon Dam and its other facilities in the CRSP system to meet this directive. Beginning in the 1990s, however, operations at each of the CRSP powerplants (Glen Canyon Dam in 1996, Flaming Gorge Dam in 2005, and the Aspinall Unit in 2012) have been restricted for environmental reasons. Although WAPA continues to dispatch these units to maximize load-following capabilities within the constraints each unit operates under, these restrictions have substantially reduced the usable generation capacity of these facilities to meet the daily and seasonal energy needs of its customers.

In addition to load/generation-following and regulation responsibilities, dispatchers follow other practices that are specific to Glen Canyon Dam Powerplant operations. These practices fall within MLFF constraints but are not ROD requirements and may be altered or abandoned by WAPA at any time. One practice involves reducing generation at Glen Canyon Dam to the same minimum level every night during low-price, off-peak hours. WAPA also avoids large changes to total daily water volume releases when they occur over successive days. This increases the efficiency of producing and marketing power at the dam and reduces downstream environmental impacts. In addition, weekend releases are generally not less than 85% of the average weekday release and, during the summer season, one cycle of raising and lowering Glen Canyon Dam Powerplant output, increasing to a maximum of two cycles during other seasons of the year as dictated by the hourly load pattern provided by customer preschedules (Poch et al. 2011).

Changes in WAPA's scheduling guidelines typically occur slowly over a period of months, not only because of the operational constraints imposed by the ROD, but also due to changing market conditions, such as persistent drought, electricity market disruptions in 2000 and 2001, and extended experimental releases that have large daily flow rate fluctuations (Poch et al. 2011).

3.13.1.6 Capacity Reserves

Each BA, or RSG utility applicable to it, is required to maintain sufficient generating capacity to continue serving its customer load, even if the BA or RSG utility loses all or part of its own largest generating unit or largest capacity transmission line. This is done to ensure electrical service reliability and uninterrupted power supply. Reserve requirements for the generation resources of the SLCA/IP are based on a formula which considers the loss of the largest single generator within the Rocky Mountain RSG and allocates a reserve quota to each member based on their relative size within the group. Total available capacity, in turn, is determined by the minimum and maximum allowable releases from these powerplants. Spinning reserves (generating units that are operating online but not generating electricity) are used to quickly replace lost electrical generation resulting from a forced outage, such as the sudden loss of a major transmission line or generating unit. Additional offline reserves (offline idle units that are ready to begin generating electricity) can be used to replace generation shortages, but they cannot respond as quickly as spinning reserves (Reclamation 1995). SLCA/IP generation resources are located within the Rocky Mountain RSG. A portion of that generation is set aside by the Rocky Mountain RSG to be utilized during contingency reserve activation periods. Capacity for this reserve obligation is held on Glen Canyon generation resources by WAPA whenever possible. (Reserve activations and subsequent water releases through the generators are not subject to the 1996 ROD release criteria.)

3.13.1.7 Disturbances and Emergencies and Outage Assistance

In the event of a widespread sudden loss of generation resource power outage, or an imbalance in the transmission system element causing a load/resource imbalance requiring an immediate response (i.e. disturbance), NERC contingency reserve standards require that available generation capacity be utilized to return the electric generation and transmission system to normal operating conditions within load/generation balance within 10 minutes following the disturbance. Generally, emergency operations contingency reserves are needed only for periods of an hour or less, but can and frequently are activated several times a day. WAPA also has existing contractual agreements to use capacity at Glen Canyon Dam to restart traditional thermal powerplants and provide emergency shutdown power to nuclear powerplants. It is especially important for generation resources at Glen Canyon Dam to be available for safe shutdown of nuclear facilities in the area in the unlikely event of a widespread power outage. WAPA’s ability to supply emergency assistance is limited by available transmission capacity and available generation capability, while the ability to deliver emergency assistance varies on an hourly basis, depending on firm load obligations and available generation from project resources. With a full reservoir and average loads, Glen Canyon Dam and Powerplant has been able to provide emergency assistance beyond its required reserves by utilizing its remaining unloaded capacity after serving load, regulation, frequency response, and contingency reserve obligations. Due to the flexibility of hydroelectric resources, the SLCA/IP has often provided scheduled outage assistance. This ability will continue into the future under all potentially selected alternatives of the LTEMP DEIS. Responding to electrical emergencies also is not subject to the 1996 ROD operating constraints.

3.13.1.8 Transmission System

The CRSP/WACM transmission system is used to transmit electricity from Glen Canyon Dam and other generating sources to customer utilities that serve end users such as municipal, residential, Tribal, irrigation district, and commercial and industrial consumers. Both hydroelectric generation and other generation resources are affected by transmission limitations when lines do not have enough capacity to transmit electricity from the point of generation to the point of demand. The amount of power scheduled for transmission varies from season to season, day to day, and hour to hour. Scheduling limits are derived from physical limits and determine how many transactions may occur. Actual transmission refers to the measured flow of power on the line. NERC requires monitoring of the actual and scheduled power flow for system operation (Reclamation 1995).

3.13.2 Power Marketing

Electricity generated at Glen Canyon Dam and Powerplant and other SLCA/IP facilities in the Upper Colorado Region is marketed by WAPA under statutory criteria in the Reclamation Project Act of 1939, the Flood Control Act of 1944, CRSPA, and the Department of Energy Organization Act of 1977, along with associated marketing plans and contractual obligations. Requirements stemming from these criteria include:

- Preference in the sale of capacity and energy must be given to municipalities, public corporations, cooperatives, and other nonprofit organizations.

- Capacity and energy must be marketed at the lowest possible rates consistent with sound business practices.

- Revenues generated from capacity and energy sales must pay for power generation and transmission facility costs (including operations, maintenance, replacements, and firming purchases and emergency power) and all allocated investment costs under the CRSPA, including interest and irrigation project expenses and investment costs related to regulating water deliveries, flood control, and water storage beyond the ability of the irrigators to repay, as well as certain environmental costs as provided under the GCPA 1992.

- Projects must generate the greatest practicable amount of capacity and energy that can be sold at firm power and energy rates.

- WAPA is responsible for the construction, operation, and maintenance of transmission lines and attendant facilities.

WAPA markets wholesale CRSP power to preference entities serving approximately 5.8 million retail customers in Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming (Reclamation 2012d). Customers are small and medium-sized municipalities that operate publicly owned electrical systems; irrigation cooperatives and water conservation districts; rural electrical associations or generation and transmission co-operatives who often act as wholesalers to these associations; federal facilities such as Air Force bases, universities, and other state agencies; and Indian Tribes (Reclamation 2012d).

For WAPA's eight largest customers in 2013, the SLCA/IP provided 6.1% of energy and 4.7% of capacity requirements; the remaining 93.9% of energy and 95.3% of capacity being provided by customer utility-owned generation facilities, or purchased from investor-owned or other utility systems, as well as other federal hydropower projects marketed by WAPA. Reliance on SLCA/IP capacity and energy varies considerably among customers; Navajo Tribal Utility Authority (27.4%) and Utah Municipal Power Agency (25.7%) received more than 25% of their energy from SLCA/IP in 2009, while three utilities, Navajo Tribal Utility Authority (19.1%), Utah Municipal Power Agency (17.8%), and Deseret Generation and Transmission Cooperative (17.8%), relied on WAPA for more than 15% of their capacity (Table 3.13-1). Other utilities, such as Tri-State G&T (1,537 GWh and 235 MW), received larger energy and capacity allocations but relied on WAPA for only a small portion of their total capacity and energy requirements.

WAPA markets long-term firm capacity and energy, short-term firm capacity and energy, and non-firm energy. Firm power is capacity and energy that are guaranteed to be available to the customer. Loads are made up of firm load, non-firm sales, and interchanges out of the control area. Firm load and capacity obligations include long- and short-term firm sales, Reclamation project use loads, system losses, BA control area regulation, firm load contingency reserves, and scheduled outage assistance. Capacity is reserved to provide regulation, contingency reserves, frequency support and response, meet CRSP contractual obligations, participating project capacity, and serve Reclamation's irrigation and drainage pumping plant loads before being marketed as long-term firm capacity. WAPA's ability to make non-firm energy sales with hydrogeneration resources after all firm power obligations have been met, and there are generation resources available for marketing purposes as water release requirements dictate, depends on SLCA/IP's flexibility to take advantage of on-peak and off-peak spot energy markets (Reclamation 1995).

The majority of CRSP power is sold under long-term firm electric service contracts. If WAPA is unable to supply contracted amounts of firm capacity or energy from Reclamation hydroelectric resources, it must purchase the deficit from other (primarily non-hydropower) resources for delivery. The expense for this purchased power is shared by all SLCA/IP customers.

Non-firm sales are short-duration energy transactions that are always less than 1 year. Normally scheduled 1 day in advance, although transactions can occur hourly, they can be determined up to the hour of transaction. These non-firm sales occur when generation patterns associated with the 1996 operating criteria do not match customer load schedules and cannot be used for firm electricity deliveries. WAPA sells the excess generation on the non-firm market to accommodate release obligations. The flexibility of hydropower operations allows actual deliveries to be modified hourly, as system conditions warrant. WAPA may market non-firm energy and arrange for interchange transactions, depending on revised water release estimates. Non-firm capacity and energy are capacity and energy that are not guaranteed to be available to

TABLE 3.13-1 Energy and Capacity Characteristics of the Eight Largest WAPA Customers, 2013[a]

Customer Utility	Energy Required (GWh)	Energy from WAPA (GWh)	Percentage of Energy from WAPA	System Peak Load (MW)	WAPA Allocation (MW)	Percentage of Load from WAPA
Colorado Springs Utilities	4,968	140	2.8	908	22	2.4
Deseret Generation and Transmission Cooperative	2,497	447	17.9	391	70	17.8
Navajo Tribal Utility Authority	718	197[b]	27.4	140[b]	27	19.1
Platte River Power Authority	3,196	536	16.8	659	71	10.7
Salt River Project	32,452	290	0.9	6,663	42	0.6
Tri-State G&T	15,313	1,537	10.0	2,666	235	8.8
Utah Municipal Power Agency	1,216	312	25.7	265	47	17.8
Utah Associated Municipal Power Systems	3,884	477	12.3	943	75	8.0
All eight customers	64,243	3,937	6.1	12,635	588	4.7

[a] Data on energy requirements and system peak load are actual values for 2013, except data for Deseret Generation and Transmission Cooperative and Navajo Tribal Utility Authority, which are forecasts for 2013.

[b] Does not include allocations received by Navajo Tribal Utility Authority from WAPA on behalf of 13 other Tribal groups.

Sources: Colorado Springs Utilities (2015); Deseret Power Cooperative (2012); Navajo Tribal Utility Authority (2012); Platte River Power Authority (2015); Salt River Project (2015); Tri-State G&T (2015); Utah Municipal Power Agency (2015); Utah Associated Municipal Power Systems (2015); Osiek (2015).

the customer, and are purchased by wholesale customers that prefer non-firm energy that is less expensive than power generated at their own powerplants or by alternative supply sources. Non-firm energy is usually sold with the caveat that the sale can be stopped on short notice and the buyer must have the resources available to meet its own load. Non-firm energy is sold at a negotiated price and delivery point based on market conditions. Rates for non-firm energy only include a charge for the energy delivered, since the customer has the capacity to meet its loads if necessary. WAPA does not sell non-firm energy on a long-term basis. The price for non-firm energy is based on market conditions (Reclamation 1995).

WAPA also offers both firm and non-firm transmission service. Firm transmission service is contractually guaranteed for the term of the agreement. Non-firm transmission service is provided as available and is not guaranteed. WAPA participates in electricity transfers, which occurs when two indirectly connected utilities agree to purchase or sell power to each other. The purchaser or seller must make arrangements to use the transmission system that connects them. WAPA offers wheeling transmission service over particular CRSP transmission paths, including lines carrying power from Glen Canyon Dam. Non-firm transmission service, like non-firm power sales, can be interrupted on short notice (Reclamation 1995).

3.13.2.1 Wholesale Rates

WAPA has long-term firm electric service contracts for SLCA/IP power with 138 Tribal entities and wholesale customers (including municipal utilities, federal and state public power facilities, and rural electric cooperatives). Power rates are established in order that revenues will be sufficient to pay all costs assigned to power within required time periods. Power revenues also pay annual power operation and maintenance, purchased power, transmission service, and interest expenses on Treasury loans used to finance construction of WAPA hydropower projects, as well as irrigation assistance beyond the ability of the irrigators to repay, along with various environmental costs, including costs of the GCDAMP and the Upper Colorado River and San Juan River Endangered Fish Recovery Implementation Programs. CRSP power revenues also must contribute toward salinity control costs under the Colorado River Basin Salinity Control Act and construction costs (with interest) of CRSP participating projects, as well as certain environmental costs as provided under the GCPA. Any remaining annual revenues are used to pay off investment costs assigned to power, so that each investment can be paid within the time allowed (Reclamation 1995).

3.13.2.2 Retail Rates

Retail rates are those paid by end users (residential, commercial, and industrial customers of WAPA's wholesale customers). The retail rates charged by not-for-profit entities normally are set to cover system operation and capital costs. As costs of these individual components change, the retail rates are adjusted to ensure enough revenue is collected to meet the utility's financial obligations.

3.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE

This section provides a brief socioeconomic background for two regions of influence: a six-county region in which the majority of recreation in the Grand Canyon area occurs and a seven-state region in which power from the Glen Canyon Powerplant is marketed. Five standard measures of economic development are described in the following sections: (1) population, (2) income, (3) total employment, (4) employment by sector, and (5) unemployment. A brief description of the numbers and locations of minority and low-income populations, including Tribal populations, in an 11-county region is also provided.

3.14.1 The Six-County Region of Influence

The six-county region is composed of Coconino County and Mohave County in Arizona, and Garfield County, Kane County, San Juan County, and Washington County in Utah. Additional socioeconomic background information on these counties can be found in DOI (2012a). Clark County, Nevada, was not included in the recreational economics analysis presented here. Although it is likely that there is some recreational expenditure in Clark County associated with recreation in Lake Mead, the share of these expenditures occurring in Clark County is not known. Expenditures were assumed to occur only in the six counties included in the analysis.

3.14.1.1 Population

Table 3.14-1 presents recent and projected populations in the region and states as a whole. The population in the region stood at 511,435 in 2012, having grown at an average annual rate of 2.4% since 2000. Washington County (4.0%), Mojave County (2.3%), and Kane County (1.5%) experienced higher growth rates than the remainder of the region, with lower growth rates in Garfield County (0.6%) and San Juan County (0.3%). The population growth rate for the region (2.4%) was slightly higher than the rates for both Arizona and Utah (2.1%) between 2000 and 2012.

TABLE 3.14-1 Population in the Six-County Region

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012	2020	2030
Coconino County, Arizona	116,320	136,011	1.3	144,300	154,400
Garfield County, Utah	4,735	5,095	0.6	6,063	6,821
Kane County, Utah	6,046	7,221	1.5	8,357	10,259
Mohave County, Arizona	155,032	203,334	2.3	241,000	285,600
San Juan County, Utah	14,413	14,965	0.3	15,644	15,486
Washington County, Utah	90,534	144,809	4.0	196,762	280,558
Six-County Region	386,900	511,435	2.4	612,126	753,124
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Governor's Office of Planning and Budget (2013).

The population in the region is expected to increase to 612,126 by 2020 and 753,124 by 2030.

3.14.1.2 Income

Personal income in the region stood at $15.1 billion in 2011 and grew at an annual average rate of 3.1% over the period from 2000 to 2011 (Table 3.14-2). Personal income per capita in the region also rose over the same period at a rate of 0.6%, increasing from $27,990 to $29,842. Per-capita incomes were higher in Coconino County ($35,685) and Kane County ($32,989) in 2011 than the average for the region as a whole. The rate of growth in personal income in the region (3.1%) was higher than the rates for Arizona (2.3%) and the same as that for Utah (2.5%) as a whole.

Average per-capita incomes in 2012 in the six-county region were lower than the averages for Arizona ($36,397) and Utah ($34,738).

Median household incomes (the income level at which exactly half of all households earn more than the level, and half earn less) over the period 2008 to 2012 varied between $42,074 (in 2013 dollars) in Mohave County and $51,622 in Coconino County (U.S. Census Bureau 2013a). Median household incomes were $50,101 for Arizona and $60,576 for Utah over the same period.

3.14.1.3 Employment

In 2012, employment in the region stood at 207,673 (Table 3.14-3). Over the period from 2000 to 2012, annual average employment growth rates were higher in Washington County (3.0%) and Mohave County (1.3%) than elsewhere in the region. At 1.6%, growth rates in the region as a whole were slightly higher than the average rates for Arizona (1.2%) and Utah (1.3%).

In 2011, the service sector provided the highest percentage of employment in the region at 53.9%, followed by wholesale and retail trade (22.3%) (Table 3.14-4). Smaller employment shares were held by manufacturing (6.6%) and construction (5.6%). Within the region, county-level employment varied somewhat across sectors compared with the region as a whole. Garfield County had a higher percentage of employment in agriculture (18.7%) and services (64.4%) than the region as a whole, while manufacturing in Coconino County (8.3%), wholesale and retail trade in Mohave County (26.6%), and services in Kane County (76.2%) were more important as employment sources than in the region as a whole.

TABLE 3.14-2 Income[a] in the Six-County Region

Location	2000	2011	Average Annual Growth Rate (%), 2000–2011
Coconino County, Arizona			
Income (billions of 2013$)	3.8	4.8	2.2
Per-capita income (2013$)	32,298	35,685	0.9
Garfield County, Utah			
Income (billions of 2013$)	0.1	0.1	1.6
Per-capita income (2013$)	25,680	28,007	0.8
Kane County, Utah			
Income (billions of 2013$)	0.2	0.2	2.5
Per-capita income (2013$)	30,195	32,989	0.8
Mohave County, Arizona			
Income (billions of 2013$)	4.1	5.5	2.7
Per-capita income (2013$)	26,249	27,045	0.3
San Juan County, Utah			
Income (billions of 2013$)	0.3	0.3	2.6
Per-capita income (2013$)	17,866	23,148	2.4
Washington County, Utah			
Income (billions of 2013$)	2.4	4.1	4.8
Per-capita income (2013$)	27,019	28,915	0.6
Six-County Region			
Income (billions of 2013$)	10.8	15.1	3.1
Per-capita income (2013$)	27,990	29,842	0.6
Arizona			
Income (billions of 2013$)	183.6	235.4	2.3
Per-capita income (2013$)	35,778	36,397	0.2
Utah			
Income (billions of 2013$)	74.4	97.8	2.5
Per-capita income (2013$)	33,333	34,738	0.4

[a] Per-capita income is income per person.

Source: U.S. Department of Commerce (2013).

TABLE 3.14-3 Employment in the Six-County Region

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012
Coconino County	59,739	67,052	1.0
Garfield County	2,301	2,454	0.5
Kane County	2,896	3,098	0.6
Mohave County	65,589	76,733	1.3
San Juan County	4,324	4,449	0.2
Washington County	37,771	53,887	3.0
Six-County Region	172,620	207,673	1.6
Arizona	2,404,916	2,778,579	1.2
Utah	1,097,915	1,276,249	1.3

Source: U.S. Department of Labor (2013).

3.14.1.4 Unemployment

Unemployment rates varied across the five counties in the region. Between 2000 and 2012, the average rate in San Juan County was 8.9% and 8.3% in Garfield County, with a relatively high rate of 6.8% in Mohave County (Table 3.14-5). The average rate in the region over this period was 6.4%, which was higher than the average rates for Arizona (5.2%) and Utah (4.0%). Unemployment rates were higher in 2012 than the average rates for the period from 2000 to 2012, with higher rates of 10.7% in San Juan County, 10.5% in Garfield County, and 9.9% in Mohave County. The average rates in 2012 for the region (8.6%) and for Arizona (8.3%) and Utah (5.7%) were also higher than the corresponding average rates for 2000 to 2012.

3.14.1.5 Environmental Justice

E.O. 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" (59 FR 7629, Feb. 11; U.S. President 1994b), formally requires federal agencies to incorporate environmental justice as part of their missions. Specifically, it directs them to address, as appropriate, any disproportionately high and adverse human health or environmental effects of their actions, programs, or policies on minority and low-income populations.

The analysis of the impacts of changes in the operation of hydropower facilities on environmental justice issues follows guidelines described in the CEQ's *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). The analysis method has three parts: (1) the geographic distribution of low-income and minority populations in the

TABLE 3.14-4 Employment by Sector in 2011[a]

	Coconino County		Garfield County		Kane County		Mohave County		San Juan County		Washington County		Six-County Region	
Employment Sector	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture[a]	628	1.4	260	18.7	141	6.3	265	0.7	226	8.3	381	1.0	1,901	1.5
Mining	60	0.1	10	0.7	10	0.4	556	1.4	110	4.0	60	0.2	806	0.6
Construction	1,932	4.3	60	4.3	76	3.4	1,932	4.8	164	6.0	2,953	8.1	7,117	5.6
Manufacturing	3,750	8.3	60	4.3	60	2.7	2,552	6.4	175	6.4	1,896	5.2	8,493	6.6
Transportation and public utilities	1,658	3.7	20	1.4	70	3.1	1,551	3.9	75	2.7	2,624	7.2	5,998	4.7
Wholesale and retail trade	8,563	19.0	176	12.6	369	16.5	10,645	26.6	492	18.0	8,236	22.6	28,481	22.3
Finance, insurance, and real estate	1,628	3.6	23	1.7	70	3.1	1,724	4.3	99	3.6	1,830	5.0	5,374	4.2
Services	25,722	57.0	896	64.4	1,702	76.2	20,744	51.9	1,475	53.9	18,511	50.7	69,050	53.9
Other	10	0.0	0	0.0	0	0.0	12	0.0	0	0.0	1	0.0	23	0.0
Total	45,143		1,392		2,234		39,998		2,738		36,485		127,990	

[a] Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

TABLE 3.14-5 Unemployment Rates (%) in the Six-County Region

Location	Average Growth Rate (%), 2000–2012	2012
Coconino County, Arizona	6.1	8.1
Garfield County, Utah	8.3	10.5
Kane County, Utah	5.5	7.2
Mohave County, Arizona	6.8	9.9
San Juan County, Utah	8.9	10.7
Washington County, Utah	5.7	7.0
Six-County Region	6.4	8.6
Arizona	5.2	8.3
Utah	4.0	5.7

Source: U.S. Department of Labor (2013).

affected area is described; (2) an assessment is conducted to determine whether the impacts of changes in operation would produce impacts that are high and adverse; and (3) if impacts are high and adverse, a determination is made as to whether these impacts disproportionately affect minority and low-income populations.

Changes in the operation of hydropower facilities and in hydropower costs could affect environmental justice if any adverse impacts on health, environmental conditions, economics, or Tribal values resulting from operational changes are determined to be high, and if these impacts would disproportionately affect minority and low-income populations, including impacts on Tribal groups. If the analysis determines that impacts on health, environmental conditions, economics, and Tribal values are not significant, there can be no disproportionate impacts on minority and low-income populations. In the event impacts are significant, disproportionality would be determined by comparing the proximity of any high and adverse impacts with the location of low-income and minority populations, including Tribal groups.

Environmental justice impacts on Tribes could occur through impacts on Tribal values or through impacts on Tribal economics. Impacts on values could result from temporary changes in access to culturally important Tribal resources associated with dam operations, and there may be an adverse impact on Tribal values from trout management actions. In addition, Tribal economics may be affected by alternative-specific differences in impacts on recreation in Glen Canyon and Grand Canyon and in the surrounding area.

The affected environment related to environmental justice issues is the 11-county region in the vicinity of the reservoirs and river corridor, and in eastern Arizona and northwestern New Mexico, which corresponds to the area in which the majority of impacts on recreation of changes in dam operations would likely occur. A description of the geographic distribution of minority and low-income groups in the affected area was based on demographic data from the 2010 Census (U.S. Census Bureau 2013b) and the 2008–2012 American Community Survey (U.S. Census Bureau 2013a). The following definitions were used to define minority and low-income population groups:

- **Minority.** Persons are included in the minority category if they identify themselves as belonging to any of the following racial groups: (1) Hispanic, (2) Black (not of Hispanic origin) or African American, (3) American Indian or Alaska Native, (4) Asian, or (5) Native Hawaiian or Other Pacific Islander.

  Beginning with the 2000 Census, where appropriate, the census form allows individuals to designate multiple population group categories to reflect their ethnic or racial origin. In addition, persons who classify themselves as being of multiple racial origins may choose up to six racial groups as the basis of their racial origins. The term "minority" includes all persons, including those classifying themselves in multiple racial categories, except those who classify themselves as not of Hispanic origin and as White or Other Race (U.S. Census Bureau 2013b).

- **Low-Income.** Individuals who fall below the poverty line. The poverty line takes into account family size and age of individuals in the family. In 2013, for example, the poverty line for a family of five with three children below the age of 18 was $27,400. For any given family below the poverty line, all family members are considered as being below the poverty line for the purposes of analysis (U.S. Census Bureau 2013b).

The CEQ guidance states that minority or low-income populations should be identified where either (1) the minority or low-income population of the affected area exceeds 50%, or (2) the minority or low-income population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis. The LTEMP EIS applies both criteria in using the Census Bureau data for census block groups, wherein consideration is given to the minority or low-income population in a census block group where the relevant population is either 50% or more of the total block group population, or where the relevant population is 20 percentage points higher than the state average (the reference geographic unit) for the relevant population.

The data in Table 3.14-6 show the minority and low-income composition of the total population located in the region, based on 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or Latino are included in the table as a separate entry. However, because Hispanics can be of any race, this number also includes individuals additionally identifying themselves as being part of one or more of the population groups listed in the table.

TABLE 3.14-6 Minority and Low-Income Populations in the 11-County Area

Population Type	Apache County, Arizona	Coconino County, Arizona	Mohave County, Arizona	Navajo County, Arizona	Cibola County, New Mexico	McKinley County, New Mexico	San Juan County, New Mexico	Garfield County, Utah	Kane County, Utah	San Juan County, Utah	Washington County, Utah	11-County Region
Total population	71,518	134,421	200,186	107,449	27,213	71,492	130,044	5,172	7,125	14,746	138,115	5,730,547
White, non-Hispanic	14,568	74,231	159,378	47,181	5,857	7,384	55,254	4,740	6,639	6,474	118,282	3,555,517
Hispanic or Latino	4,113	18,166	29,569	11,571	9,934	9,473	24,776	234	263	649	13,486	1,433,977
Non-Hispanic or Latino minorities	52,837	42,024	11,239	48,697	11,422	54,635	50,014	198	223	7,623	6,347	741,051
One race	51,753	39,222	7,985	47,047	11,077	53,329	47,564	161	153	7,371	4,161	646,795
Black or African American	157	1,495	1,715	842	221	317	617	13	15	21	632	67,458
American Indian or Alaskan Native	51,360	35,610	3,793	45,551	10,680	52,402	46,321	75	103	7,308	1,460	457,112
Asian	185	1,787	2,016	542	136	542	445	61	31	35	954	87,215
Native Hawaiian or other Pacific Islander	24	138	316	68	19	17	64	10	1	5	1,022	26,839
Some other race	27	192	145	44	21	51	117	2	3	2	93	8,171
Two or more races	1,087	2,802	3,254	1,650	345	1,306	2,450	37	70	252	2,186	94,256
Total minority	56,950	60,190	40,808	60,268	21,356	64,108	74,790	432	486	8,272	19,833	2,175,028
Low-income	19,838	23,050	37,426	24,061	6,468	19,985	20,576	628	539	4,103	20,225	729,333
Percent minority	76.9	44.8	20.4	56.1	78.5	89.7	57.5	8.4	6.8	56.1	14.4	38.0
State percent minority	42.2	42.2	42.2	42.2	59.5	59.5	59.5	19.6	19.6	19.6	19.6	–[a]
Percent low-income	27.7	17.2	18.6	22.4	23.7	27.8	16.0	12.3	7.6	27.9	14.5	12.7
State percent low-income	12.4	12.4	12.4	12.4	14.9	14.9	14.9	12.1	12.1	12.1	12.1	–

[a] A dash indicates not applicable.

A large number of minority and low-income individuals are located in the 11-county area around the Glen Canyon and Grand Canyon. Within the area, 38.0% of the population is classified as minority, while 12.7% is classified as low-income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in a state, for example), rather than only on the number of minority and low-income individuals present in a geographic area. The number of minority individuals exceeds the state average by 20 percentage points or more in Apache County, Arizona; McKinley County, New Mexico; and San Juan County, Utah; and exceeds 50% of the total population in Apache County and Navajo County, Arizona; in Cibola County, McKinley County, and San Juan County, New Mexico; and in San Juan County, Utah; meaning that there are minority populations in each of these counties based on CEQ guidelines and on county-level data in the 2010 Census and 2008–2012 American Community Survey data. As the number of low-income individuals does not exceed the state average by more than 20 percentage points, or does not exceed 50% of the total population in any of the 11 counties, there are no low-income populations based on county-level data in the 11-county region.

Within each county, there are block groups with minority and low-income populations. Figures 3.14-1 and 3.14-2 show the locations of the minority and low-income population groups in the 11-county area.

A large number of block groups in the 11-county area have populations whose percentage of minority individuals is more than 20 percentage points higher than the state average. In the Arizona counties, these block groups are located in the eastern part of Coconino County on the Navajo Nation Indian Reservation and the Hopi Indian Reservation; in the western part of Coconino County, which includes the Havasupai Indian Reservation and the Hualapai Indian Reservation, which are also located in one block group in eastern Mohave County. The Navajo Nation Indian Reservation and the Hopi Indian Reservation are also located in the central and northern part of Apache County, which also contains the Fort Apache Indian Reservation in the southern part of the county. The Navajo Nation Indian Reservation is also located in the central and northern part of Navajo County, Arizona, and in the western part of San Juan County, New Mexico. In all census block groups in these areas, the number of minority individuals is higher than the state average by 20 percentage points or more. Elsewhere in New Mexico, eastern San Juan County, a large majority of McKinley County, which contains part of the Navajo Nation Indian Reservation, part of the Zuni and Ramah Navajo Indian Reservations, and parts of Cibola County, which contains parts of the Ramah Navajo Indian Reservations, and the Acoma, Canoncito and Laguna Indian Reservations, all have block groups whose percentage of minorities is more than 20 percentage points higher than the state average.

There are a number of census block groups in the 11-county area in which more than 50% of the total population is minority. These are located in the southern portion of San Juan County, Utah, which includes the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; the western part of Cibola County, which includes the Zuni Indian Reservation; and the eastern part of the Cibola County, which includes the Acoma, Canoncito and Laguna Indian Reservations. Census block groups in Page, Winslow, and Holbrook,

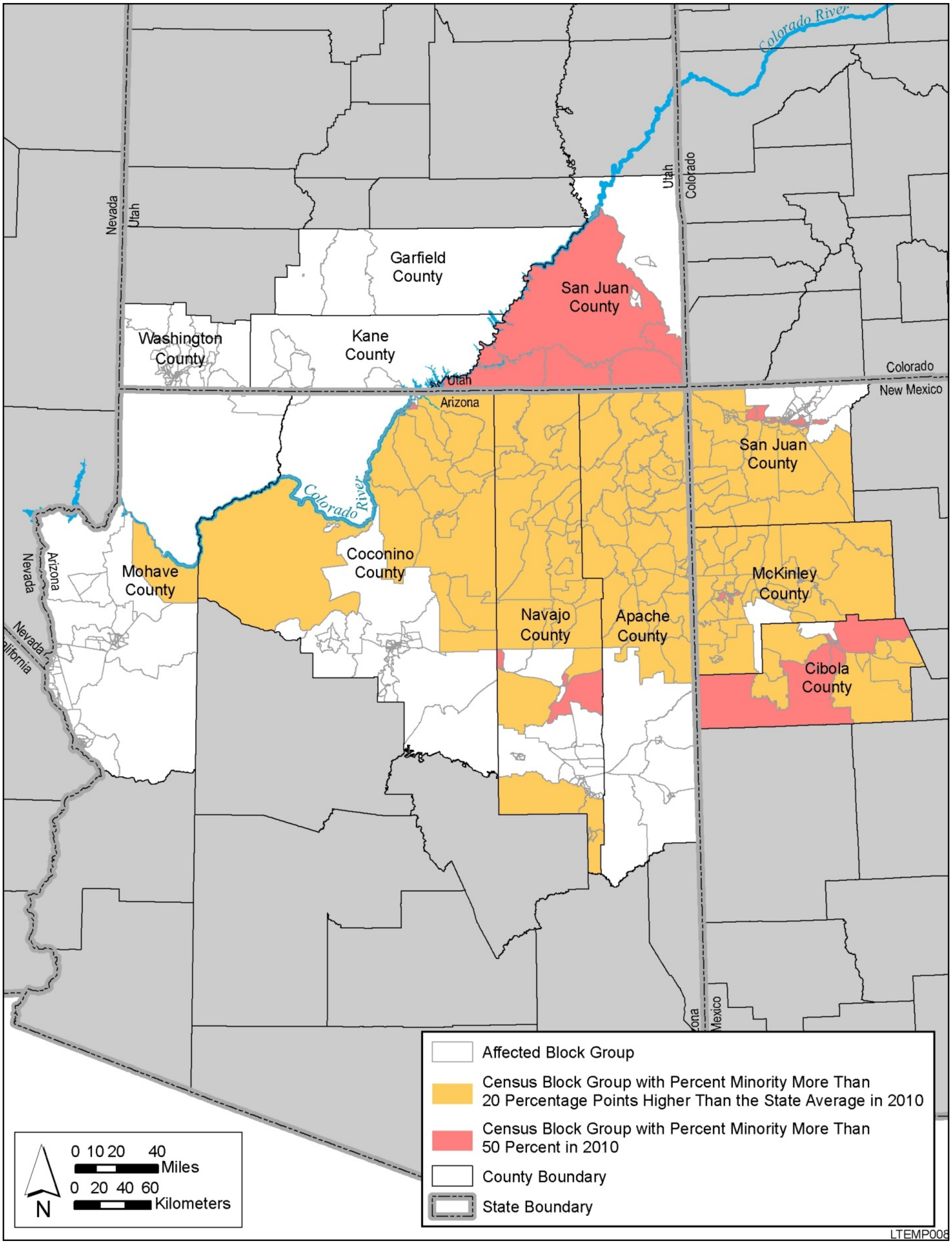

FIGURE 3.14-1 Minority Population Groups in the 11-County Area

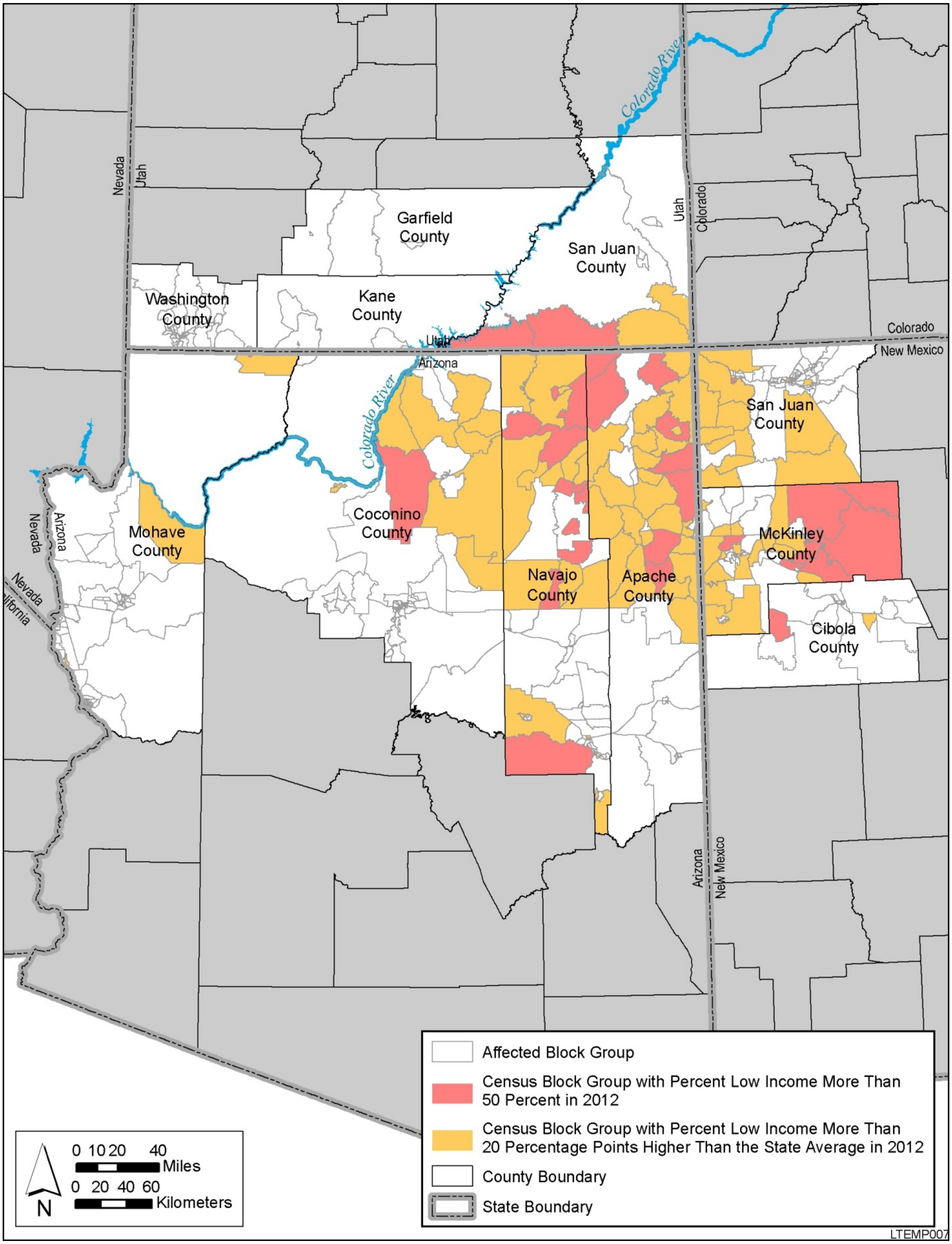

FIGURE 3.14-2 Low-Income Population Groups in the 11-County Area

Arizona, also have minority populations that are more than 50% of the total, as do census block groups in, and in the vicinity of, Farmington and Shiprock, New Mexico

There are a large number of census block groups in the 11-county area in which the percentage of low-income individuals is more than 20 percentage points higher than the state average. These are located on the Navajo Nation Indian Reservation and the Hopi Indian Reservation in Coconino County and on the Navajo Nation Indian Reservation in Navajo County, Arizona, which also contains the Fort Apache Indian Reservation; and in Apache County, Arizona, and San Juan County, New Mexico, on the Navajo Nation Indian Reservation. There are also block groups in McKinley County, New Mexico, on the Zuni Indian Reservation and in the vicinity of Gallup; in southeastern San Juan County, New Mexico; in eastern Mohave County, Arizona, on the Hualapai Indian Reservation; in southeastern and southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation, where the percentage of low-income individuals is more than 20 percentage points higher than the state average.

There are also a number of census block groups in the 11-county area in which more than 50% of the total population is below the poverty level. These are located in the eastern part of Coconino County, Arizona, on the Navajo Nation Indian Reservation and Hopi Indian Reservation; in southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; in the northern parts of Navajo County and Apache County, Arizona; in southwestern Navajo County on the Fort Apache Indian Reservation; in New Mexico, in the eastern part of McKinley County, in the vicinity of Gallup, and on the Ramah Navajo Indian Reservation in Cibola County, New Mexico.

3.14.2 The Seven-State Region of Influence

This section describes current socioeconomic conditions within the seven-state region, the area in which electricity from Glen Canyon Dam is marketed, including Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming.

3.14.2.1 Population

Total population in the seven-state region was 21.9 million people in 2012, an increase from 17.7 million in 2000 (Table 3.14-7). Population in the region is concentrated in Arizona and Colorado, which, at 11.7 million people, had almost 54% of the total regional population in 2012.

Population in the seven-state study area grew at an annual average rate of 1.8% from 2000 to 2012. Growth within the region was uneven over the period, with higher than average annual growth rates in Nevada (2.7%), Arizona (2.1%), and Utah (2.1%). Growth rates in Colorado (1.6%) were closer to the average for the region, with lower than average rates in Wyoming (1.3%), New Mexico (1.1%), and Nebraska (0.7%).

TABLE 3.14-7 Population in the Seven-State Region of Influence

State	2000	2012	Annual Growth Rate (%), 2000–2012	2020	2030
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Colorado	4,301,261	5,187,582	1.6	5,915,922	6,888,181
Nebraska	1,711,263	1,855,525	0.7	1,940,114	2,054,752
Nevada	1,998,257	2,798,931	2.7	2,959,641	3,222,107
New Mexico	1,819,046	2,085,538	1.1	2,351,724	2,613,332
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984
Wyoming	493,782	576,412	1.3	622,360	668,830
Total	17,687,410	21,872,530	1.8	24,583,995	28,214,986

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Colorado Department of Local Affairs (2013); Nebraska Department of Economic Development (2013); Nevada State Demographer's Office (2013); University of New Mexico (2013); Governor's Office of Planning and Budget (2013); Wyoming Department of Administration and Information (2013).

The regional population is projected to reach 24.6 million in 2020 and 28.2 million 2030.

3.14.2.2 Income

Arizona and Colorado generated almost 55% of the income in the seven-state region, together producing almost $469 billion in 2011 (Table 3.14-8). Personal income grew at an annual average rate of 2.0% over the period from 2000 to 2011, with higher than average growth rates in Wyoming (3.4%), New Mexico (2.5%), Utah (2.5%), and Arizona (2.3%). Income per capita rose slightly over the same period at a rate of 0.2%, resulting in an increase from $38,640 to $39,509. Per capita incomes were higher in 2011 in Wyoming ($49,676), Colorado ($45,628), and Nebraska ($43,973) than the average for the region as a whole.

Median household incomes (the income level at which exactly half of all households earn more than the level, and half earn less) over the period from 2008 to 2012 varied between $45,542 in New Mexico and $59,096 in Colorado (U.S. Census Bureau 2013a). Median household income in the United States was $53,832 over the same period.

TABLE 3.14-8 Income in the Seven-State Region of Influence

State	2000	2011	Average Annual Growth Rate (%), 2000–2011
Arizona			
Income (billions of 2013$)	183.6	235.4	2.3
Per-capita income (2013$)	35,778	36,397	0.2
Colorado			
Income (billions of 2013$)	198.9	233.4	1.5
Per-capita income (2013$)	46,252	45,628	–0.1
Nebraska			
Income (billions of 2013$)	66.3	81.0	1.8
Per-capita income (2013$)	38,735	43,973	1.2
Nevada			
Income (billions of 2013$)	84.6	104.3	1.9
Per-capita income (2013$)	42,337	38,328	-0.9
New Mexico			
Income (billions of 2013$)	56.0	73.6	2.5
Per-capita income (2013$)	30,808	35,410	1.3
Utah			
Income (billions of 2013$)	74.4	97.8	2.5
Per-capita income (2013$)	33,333	34,738	0.4
Wyoming			
Income (billions of 2013$)	19.6	28.2	3.4
Per-capita income (2013$)	39,626	49,676	2.1
Total			
Income (billions of 2013$)	683.4	853.7	2.0
Per-capita income (2013$)	38,640	39,509	0.2

Source: U.S. Department of Commerce (2013).

3.14.2.3 Employment

In 2012, more than 53% (5.3 million) of all employment in the seven-state power marketing service territory (9.9 million) was concentrated in Arizona and Colorado (Table 3.14-9). Employment in Utah was 1.3 million and 1.2 million in Nevada, the remaining states supporting 2.1 million jobs. Over the period from 2000 to 2012, annual employment growth rates were higher in Nevada (1.6%) and Utah (1.3%) than elsewhere in the seven-state study area, with rates in Colorado (0.8%), New Mexico (0.6%), and Nebraska (0.5%) lower than the average rate of 1.0%.

In 2011, the service sector provided the highest percentage of employment in the seven-state region at almost 56%, followed by wholesale and retail trade (17.5%) (Table 3.14-10). Smaller employment shares were held by finance, insurance, and real estate (6.9%), and both construction and manufacturing (6.7%). Within the region, the distribution of employment across sectors varied somewhat compared to the region as a whole. Nebraska (5.7%) and Wyoming (4.6%) have a higher percentage of employment in agriculture than the region as a whole (2.2%), and these states have lower shares of employment in services compared with the region as a whole. Service sector employment in Nevada (62.9%) and Colorado (58.6%) is higher than in the region as a whole. Nebraska (10.8%) and Utah (10.2%) have larger than average shares of manufacturing sector employment, while mining is a more significant employer in Wyoming (12.4%) than elsewhere in the region.

TABLE 3.14-9 Employment in the Seven-State Region of Influence

State	2000	2012	Average Annual Growth Rate (%), 2000–2012
Arizona	2,404,916	2,778,579	1.2
Colorado	2,300,192	2,523,535	0.8
Nebraska	923,198	980,668	0.5
Nevada	1,015,221	1,226,408	1.6
New Mexico	810,024	871,299	0.6
Utah	1,097,915	1,276,249	1.3
Wyoming	256,685	289,621	1.0
Total	8,808,151	9,946,359	1.0

Source: U.S. Department of Labor (2013).

TABLE 3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence[a]

	Arizona		Colorado		Nebraska		Nevada		New Mexico		Utah		Wyoming		Total	
Sector	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture[a]	30,113	1.4	40,673	2.0	48,061	5.7	4,603	0.5	23,426	3.8	20,175	1.9	10,029	4.6	177,080	2.2
Mining	11,160	0.5	25,006	1.2	963	0.1	11,484	1.1	16,643	2.7	10,755	1.0	27,001	12.4	103,012	1.3
Construction	116,992	5.5	115,615	5.7	37,196	4.4	50,140	5.0	39,441	6.4	56,030	5.3	17,350	8.0	432,764	5.5
Manufacturing	137,532	6.4	117,810	5.9	91,190	10.8	39,277	3.9	27,434	4.4	106,865	10.2	9,644	4.4	529,752	6.7
Transportation and public utilities	87,613	4.1	68,901	3.4	38,583	4.6	48,147	4.8	21,385	3.4	50,294	4.8	13,861	6.4	328,784	4.2
Wholesale and retail trade	398,228	18.6	332,919	16.6	146,784	17.4	163,369	16.3	115,071	18.5	187,284	17.9	37,926	17.4	1,381,581	17.5
Finance, insurance, and real estate	168,747	7.9	132,273	6.6	68,097	8.1	57,788	5.7	31,848	5.1	76,448	7.3	10,925	5.0	546,126	6.9
Services	1,186,730	55.5	1,177,687	58.6	413,514	49.0	632,580	62.9	345,254	55.6	540,136	51.5	92,500	42.4	4,388,401	55.6
Other	175	0.0	375	0.0	60	0,0	175	0.0	62	0.0	60	0.0	75	0.0	982	0.0
Total	2,137,315		2,011,186		844,678		1,005,038		620,564		1,048,851		218,211		7,885,843	

[a] Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

3.14.2.4 Unemployment

Between 2000 and 2011, average unemployment rates have varied across the seven-state region, from 7.7% in Nevada and 6.5% in Arizona to lower rates elsewhere in the region, particularly in Nebraska (3.8%) (Table 3.14-11). The average rate in the region over this period was 6.2%. Rates were higher in 2012 than average rates for the period from 2000 to 2011, unemployment standing at 11.1% in Nevada and 8.3% in Arizona, with lower rates in the other five states; the average rate for the region as a whole (7.6%) was also higher during this period than the corresponding average rate for 2000 to 2011.

3.14.2.5 Environmental Justice

The data in Table 3.14-12 show the minority and low-income composition of total population located in the seven-state region based on 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or Latino are included in the table as a separate entry. However, because Hispanics can be of any race, this number also includes individuals also identifying themselves as being part of one or more of the population groups listed in the table.

TABLE 3.14-11 Unemployment in the Seven-State Region of Influence[a]

State	Average Rate (%), 2000–2011	2012 (%)
Arizona	6.5	8.3
Colorado	6.0	8.0
Nebraska	3.8	3.9
Nevada	7.7	11.1
New Mexico	5.7	6.9
Utah	5.0	5.7
Wyoming	4.5	5.4
Total	6.2	7.6

Source: U.S. Department of Labor (2013).

TABLE 3.14-12 State Minority and Low-Income Populations, 2010

Category	Arizona	Colorado	Nebraska	Nevada	New Mexico	Utah	Wyoming	Region Total
Total population	6,392,017	5,029,196	1,826,341	2,700,551	2,059,179	2,763,885	563,626	21,334,795
White, Non-Hispanic	3,695,647	3,520,793	1,499,753	1,462,081	833,810	2,221,719	483,874	13,717,677
Hispanic or Latino	1,895,149	1,038,687	167,405	716,501	953,403	358,340	50,231	5,179,716
Non-Hispanic or Latino minorities	801,221	469,716	159,183	521,969	271,966	183,826	29,521	2,437,402
One race	686,590	368,869	130,757	442,837	242,131	134,841	21,216	2,027,241
Black or African American	239,101	188,778	80,959	208,058	35,462	25,951	4,351	782,660
American Indian or Alaska Native	257,426	31,244	14,797	23,536	175,368	27,081	11,784	541,236
Asian	170,509	135,564	31,919	191,047	26,305	54,176	4,279	613,799
Native Hawaiian or other Pacific Islander	10,959	5,661	966	15,456	1,246	23,909	365	58,562
Some other race	8,595	7,622	2,116	4,740	3,750	3,724	437	30,984
Two or more races	114,631	100,847	28,426	79,132	29,835	48,985	8,305	410,161
Total minority	2,696,370	1,508,403	326,588	1,238,470	1,225,369	542,166	79,752	7,617,118
Low-income	1,094,249	659,786	229,923	398,027	413,851	359,242	61,577	3,216,655
Percent minority	42.2	30.0	17.9	45.9	59.5	19.6	14.1	35.7
U.S. Percent	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3
Percent low-income	17.4	13.4	12.9	14.9	20.4	13.2	11.2	15.1
U.S. percent	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8

Sources: U.S. Census Bureau (2013a,b).

A large number of minority and low-income individuals are located in the seven-state region in which electricity from Glen Canyon dam is marketed. In the region as whole, 35.7% of the population is classified as minority, while 15.1% is classified as low-income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in the nation, for example), rather than only on the number of minority and low-income individuals present in a geographic area. The number of minority or low-income individuals in the seven-state region does not exceed the respective national averages by 20 percentage points or more, and does not exceed 50% of the total population in the area, meaning that for the region as a whole, there are no minority or low-income populations based on CEQ guidelines and on 2010 Census and 2008–2012 American Community Survey data. However, within one state in the region, New Mexico, 59.5% of the total population is minority, meaning that according to 2010 Census and 2008–2012 American Community Survey data, there is a minority population in the state.

Although there are no minority populations in any of the seven states, except for New Mexico, and no low-income populations, there are a large number of Native American individuals in the seven-state area, many of whom reside on Tribal Reservations. Section 3.9 provides more information on the location and Tribal population associated with Reservations. Many of these individuals are low-income in status.

Tribal members receive a significant portion of their electricity from WAPA, which currently targets an allocation of 65% of total Tribal electrical use to the 57 Tribes or Tribal entities currently receiving an allocation of power from the SLCA/IP system, which includes power from Glen Canyon Dam. Nine of these Tribes operate electric utilities and receive power directly from WAPA, while the remaining 48 Tribes can often benefit from cheaper federal hydropower through “benefit crediting” arrangements with SLCA/IP customers or other electric utilities. Benefit credits are provided to a Tribe by the utility that serves the area in which the Tribe is located in lieu of direct electric service by WAPA, and are intended to be the financial equivalent of a direct allocation. When the SLCA/IP rate is lower than the rate charged for electrical power by the utility, the difference between the two rates is paid to each Tribe by subtracting the amount of the benefit credit, pro-rated by the amount of electricity consumed, from the monthly electric bill.

3.14.3 Non-Use Value

Non-use values are economic values that may be placed on the status of the natural or physical environment by non-users, or individuals who may never visit or otherwise use a natural resource that might still be affected by changes in its status or quality, who may assign a non-use or passive-use economic value to a resource.

Welsh et al. (1995) estimated the willingness to pay to improve native vegetation, native fishes, game fish, river recreation, and cultural sites in Glen Canyon National Recreation Area and Grand Canyon National Park. Value estimates varied between $17.74 and $26.91 for a U.S. household, and between $29.05 and $38.02 for a western U.S. household.

Understanding non-market values affected by proposed operational changes at Glen Canyon Dam, for both recreational use and environmental non-use values, has been the topic of considerable prior investigations (e.g., Bishop et al. 1987; Welsh et al. 1995). These studies have been important in bringing non-market values into consideration for managing the resources of the Colorado River Basin (Harpman et al. 1995; Loomis et al. 2005). In that regard, two additional studies (Loomis 2014; Jones et al. 2016) have been conducted regarding non-market values.

Loomis (2014) concluded that there is a theoretical basis for non-market values associated with hydropower and water. He used the example of how people can place value on maintaining the ranching and farming way of life associated with western rural communities as irrigated agriculture landscapes are correlated with open space. In addition, people may place value on the existence and well-being of farming communities. Indirect empirical support for altruism toward farmers is cited in Loomis (2014). Non-market values associated with hydropower and water resources may also exist to the extent hydropower and developed water assist in the maintenance of Tribal values and social well-being.

3.15 AIR QUALITY

Air quality is primarily affected by air emission sources, both natural (e.g., wildfires and windblown dust) and man-made (e.g., power generation from fossil fuel–fired plants, such as the nearby Navajo Generating Station, and potentially other plants in the 11-state area, as well as onroad and offroad mobile sources such as vehicles).

Changes in operations at Glen Canyon Dam can create either more or less hydroelectricity at certain times of the day to meet regional electricity demand. If less electricity is available at Glen Canyon Dam, demand must be met by other means, which may include powerplants fueled by fossil fuels (including coal, oil, and gas turbine plants) and nuclear, other hydroelectric, wind, and solar energy sources, or by demand-side management. Changes in the operation of Glen Canyon Dam, therefore, may indirectly affect air quality by potentially changing the degree to which electricity demand is met within the region, with either non-emission hydropower, wind, or solar powerplants, or emission-producing powerplants, such as fossil fuel–fired powerplants that can directly affect air quality and related resources. These air quality changes can also affect greenhouse gas (GHG) emissions that can influence climate change. Local and regional GHG information is presented here, while climate change is discussed in Section 3.16.

3.15.1 Local Air Quality

The Clean Air Act (CAA), as amended (42 USC 7401) established Prevention of Significant Deterioration (PSD) provisions for use in protecting the nation's air quality and visibility. The PSD provisions apply to new or modified major stationary sources and are designed to keep an attainment area in continued compliance with the National Ambient Air Quality Standards (NAAQS). Major stationary sources are industrial-type facilities and include powerplants and manufacturing facilities that emit more than 100 tons per year of a regulated pollutant. No major stationary sources are being proposed for construction or modification by the proposed federal action; therefore the statutory provisions specific to PSD are not applicable. However, there are criteria pollutants for which thresholds for increases in pollution concentrations have been established. These include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter (PM), which are often analyzed. The PSD standards are most stringent in Class I areas and are progressively less stringent in the Class II and Class III areas (Table 3.15-1). GCNRA and LMNRA are designated as Class II areas, while GCNP is designated as a Class I area.

Table 3.15-2 presents criteria pollutant and volatile organic compound (VOC) emission totals in 2011 for Coconino and Mohave Counties (EPA 2013a), which encompass the GCNP. The data represent 13 source categories (e.g., fuel combustion by power generation and industry, highway vehicles, off-highway vehicles, and miscellaneous sources). Miscellaneous sources, including prescribed/structural fires, wildfires, fugitive dust, and agricultural production, account for a predominant portion of the two-county totals of PM with an aerodynamic diameter less than or equal to 2.5 μm ($PM_{2.5}$), particulate matter with an aerodynamic diameter less than or equal to 10 μm (PM_{10}), and SO_2. In addition, miscellaneous sources are primary contributors to carbon monoxide (CO) and VOC emissions, which account for more than 50% of their respective total emissions. Highway vehicles are primary contributors to total NO_x emissions and secondary contributors to total CO emissions. Off-highway vehicles are secondary contributors to total NO_x and VOC emissions. In these counties, fuel combustion and industrial activities are minor contributors to any criteria pollutant and VOC emissions.

TABLE 3.15-1 Clean Air Act Prevention of Significant Deterioration Designations

Designation	Definition
Class I Area	Visibility is protected more stringently than under the NAAQS; includes national parks, wilderness areas, monuments, and other areas of special national and cultural significance.
Class II Area	Moderate change is allowed, but stringent air quality constraints are nevertheless desired.
Class III Area	Substantial industrial or other growth is allowed, and increases in concentration up to the national standards would be considered insignificant.

TABLE 3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand Canyon National Park and for the Navajo Generating Station, 2011

	Annual Emissions (10^3 tons)[a]					
County/Facility	CO	NO_x	VOCs	$PM_{2.5}$	PM_{10}	SO_2
Coconino	117.41	14.24	26.17	8.98	17.76	0.67
Mohave	48.77	12.79	10.97	2.55	12.65	0.13
Two-county total	166.19	27.03	37.13	11.52	30.41	0.80
Navajo Generating Station[b]	1.96	19.84	0.03	2.83	4.11	4.64

[a] CO = carbon monoxide; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter with an aerodynamic diameter of ≤ 2.5 μm; PM_{10} = particulate matter with an aerodynamic diameter of ≤ 10 μm; SO_2 = sulfur dioxide; and VOC = volatile organic compound.

[b] The 2,250-MW coal-fired powerplant is located on the Navajo Indian Reservation near Page, Arizona, which is within Coconino County. Emissions from the Navajo Generating Station are not included in Coconino County emission totals.

Source: EPA (2013a).

Data on emissions from Tribal lands in Coconino and Mohave Counties are hard to find because the emission data are given in total emissions for Tribal lands which straddle many counties and even many states. One important point source within the area is the Navajo Generating Station, a 2,250-MW coal-fired powerplant located on the Navajo Indian Reservation near Page, Arizona (within Coconino County). NO_x emissions from this powerplant are about three-fourths of the two-county emissions combined, while SO_2 emissions are much larger (Table 3.15-2). There are three natural gas–fired powerplants in southwestern Mohave County but none in Coconino County.

3.15.2 Regional Air Quality

Changes in operations at Glen Canyon Dam can affect regional air quality if these changes result in corresponding increases or decreases in power generation at other facilities in the Western Interconnection grid. Under the CAA, the U.S. Environmental Protection Agency (EPA) has established the NAAQS for six criteria pollutants considered harmful to public health and the environment (40 CFR Part 50): SO_2, NO_2, CO, ozone (O_3), $PM_{2.5}$, PM_{10}, and lead (Pb) (EPA 2015a). Each state in this 11-state area can have its own State Ambient Air Quality Standards (SAAQS) for criteria pollutants. If a state has no standard corresponding to one of the NAAQS or a standard less stringent than NAAQS, the NAAQS apply. In addition, any state can establish standards for pollutants other than criteria pollutants. Several states have adopted standards for additional pollutants: visibility-reducing particles, sulfates, hydrogen sulfide (H_2S), and vinyl chloride for California; fluorides for Idaho; H_2S, settled PM, and fluoride in forage for Montana;

H_2S for Nevada; total suspended particulates, H_2S, and total reduced sulfur for New Mexico; particle fallout for Oregon; radionuclides and fluorides for Washington; and H_2S, suspended sulfates, fluorides, and odors for Wyoming.

Parts of the 11-state area have not yet attained the NAAQS for SO_2, 8-hour O_3, $PM_{2.5}$, PM_{10}, and Pb, as shown in Figure 3.15-1 (EPA 2015b). Currently, there are no nonattainment areas for NO_2 and CO in the United States, and thus in the 11-state area. Except for Washington, each state has one or more nonattainment areas. Arizona has nonattainment areas for all five air pollutants, while California and Montana have nonattainment areas for four air pollutants. In contrast, Washington has no nonattainment areas. Utah has nonattainment areas for three air pollutants. Three states (Idaho, Oregon, and Wyoming) have nonattainment areas for two air pollutants, while three states (Colorado, Nevada, and New Mexico) have nonattainment areas for one air pollutant. Nonattainment areas are mostly located in urban areas, except for the rural environment of the Upper Green River Basin in southwestern Wyoming, due to high wintertime ozone.

There are many regional air pollution problems such as O_3, acid deposition, and visibility degradation in the western United States. Ozone issues are most prevalent around urban centers, with the exception of elevated wintertime O_3 at higher elevations near oil and gas fields in Utah, Wyoming, and Colorado, where snow cover is prevalent. Impacts of acid deposition have been observed in the Desert Southwest, where excess nitrogen deposition facilitates invasion of nonnative grass species that compete with native plant species and increase fire risk due to increased biomass fuel loading. Acid deposition may also affect high-elevation lakes where excess nitrogen deposition can alter aquatic species composition. Visibility impairment is a widespread and pervasive problem throughout the country, and, in particular, in many national parks and wilderness areas where the CAA specifically requires visibility protection.

Visibility degradation is caused by cumulative emissions of air pollutants from a myriad of sources scattered over a wide geographical area. In general, the primary cause of visibility degradation is the scattering and absorption of light by fine particles, with a secondary contribution provided by gases. In general, visibility conditions in the western United States are substantially better than those in the eastern United States because of the higher pollutant loads and humidity levels in the East (EPA 2006). The typical visual range (defined as the farthest distance at which a large black object can be seen and recognized against the background sky) in most of the western United States is about 60 to 90 mi, while that in most of the eastern United States is about 15 to 30 mi. Most visibility degradation is associated with combustion-related sources, while fugitive dust sources contribute to some extent. In particular, smaller particles such as $PM_{2.5}$ scatter light more efficiently, which includes ammonium sulfate, ammonium nitrate, particulate organic matter, light-absorbing carbon (or soot), mineral fine soil, and sea salt. Ammonium sulfate and ammonium nitrate are formed by chemical reactions in the atmosphere that include emissions of SO_2 and NO_x, respectively. Particulate organic matter (POM) can be emitted directly from vegetation or can form in the atmosphere from a variety of gaseous organic compounds. At the GCNP, POM has the greatest impact on visibility, followed by ammonium sulfate (Hand et al. 2011).

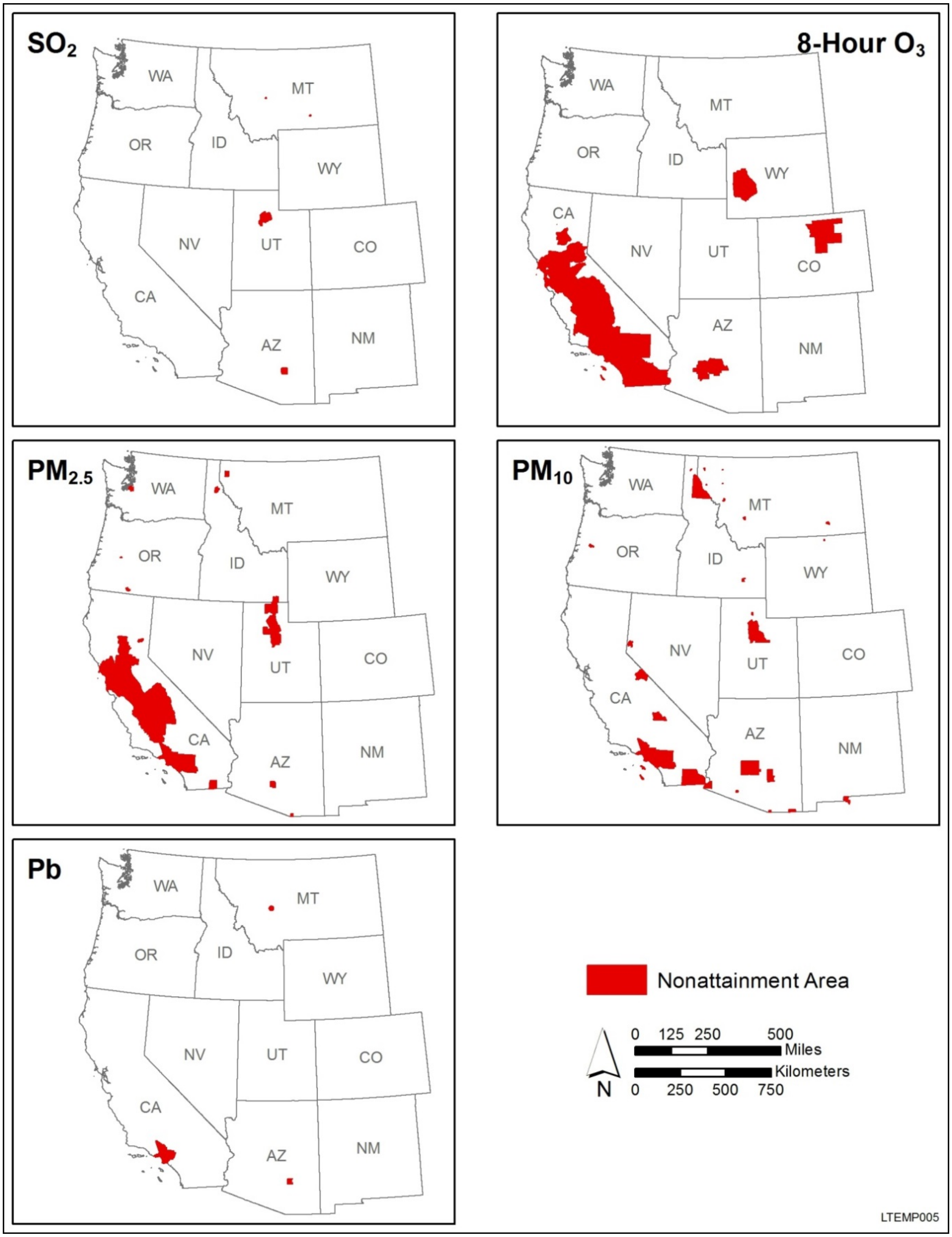

FIGURE 3.15-1 Nonattainment Areas for SO_2, 8-Hour O_3, $PM_{2.5}$, PM_{10}, and Pb in the 11-State Area (Note that currently there are no nonattainment areas for NO_2 and CO in the United States and thus in the 11-state area.) (Source: EPA 2015b)

Visibility was singled out for particular emphasis in the CAA Amendments (CAAA) of 1977. Visibility in a Class I area is protected under two sections of the CAAA. Section 165 provides for the PSD program (described in Section 3.15.2) for new sources. Section 169(A), for older sources, describes requirements for both reasonably attributable single sources and regional haze, which address multiple sources. Federal land managers have a particular responsibility to protect visibility in Class I areas. There are 158 mandatory federal Class I areas in the United States, and those in the 11-state area are illustrated in Figure 3.15-2 (EPA 2013b).

In 1999, the EPA issued the final Regional Haze Rule (64 FR 35714, July 1, 1999) which sets a national visibility goal for preventing future and remedying existing impairment to visibility in Class I areas. The rule is designed to reduce visibility impairment from existing sources and limit visibility impairment from new sources. States with Class I areas or states affecting visibility in Class I areas must revise their state implementation plans, prepare emission-reduction strategies to reduce regional haze, and establish glide paths for each Class I area. States are required to periodically review whether they are making reasonable progress toward meeting the goal of achieving natural conditions by 2064. Wildfires and windblown dust storms can significantly degrade visibility at Class I areas in the 11-state area. Emissions of SO_2 and NO_x from fossil fuel combustion are the major man-made causes of visibility impairment; these emissions have been substantially reduced in the 11-state area in the past decade in response to state and federal requirements (ARS 2013).

3.15.3 Regional Air Emissions

Table 3.15-3 presents statewide criteria pollutants and VOC emissions for the 11-state area within the Western Interconnection in 2011 (EPA 2013a). As discussed in Section 3.15.2, emission data are given in 13 source categories. Overall, miscellaneous sources are primary contributors to CO, $PM_{2.5}$, PM_{10}, and VOCs for the 11-state totals. Highway vehicles and fuel combustion for electricity generation are primary contributors to NO_x and SO_2, which account for about 45% and 41% of the 11-state total emissions, respectively. Among the 11 states in the region, all criteria pollutants and VOC emissions, except PM_{10} and SO_2, are highest in California. PM_{10} emissions are highest in New Mexico. SO_2 emissions are highest in Wyoming, which burns large quantities of fossil fuel (notably coal) for power generation and industrial activities. Total criteria pollutant and VOC emissions combined are highest in California followed by Arizona, and lowest in Nevada.

Table 3.15-3 also shows total statewide gross[13] GHG emissions on a consumption basis in terms of carbon dioxide equivalent (CO_2e).[14] GHG emissions for California are the highest at 453.1 million metric tons (MMt) (499.5 million tons) CO_2e, followed by Colorado, while those

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[13] Excluding GHG emissions removed due to forestry and other land uses.

[14] The carbon dioxide equivalent is a measure used to compare the emissions from various GHGs on the basis of their global warming potential (GWP), which is defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period. For example, GWP is 21 for CH_4, 310 for N_2O, and 23,900 for SF_6. Accordingly, CO_2e emissions are estimated by multiplying the mass of a gas by the GWP.

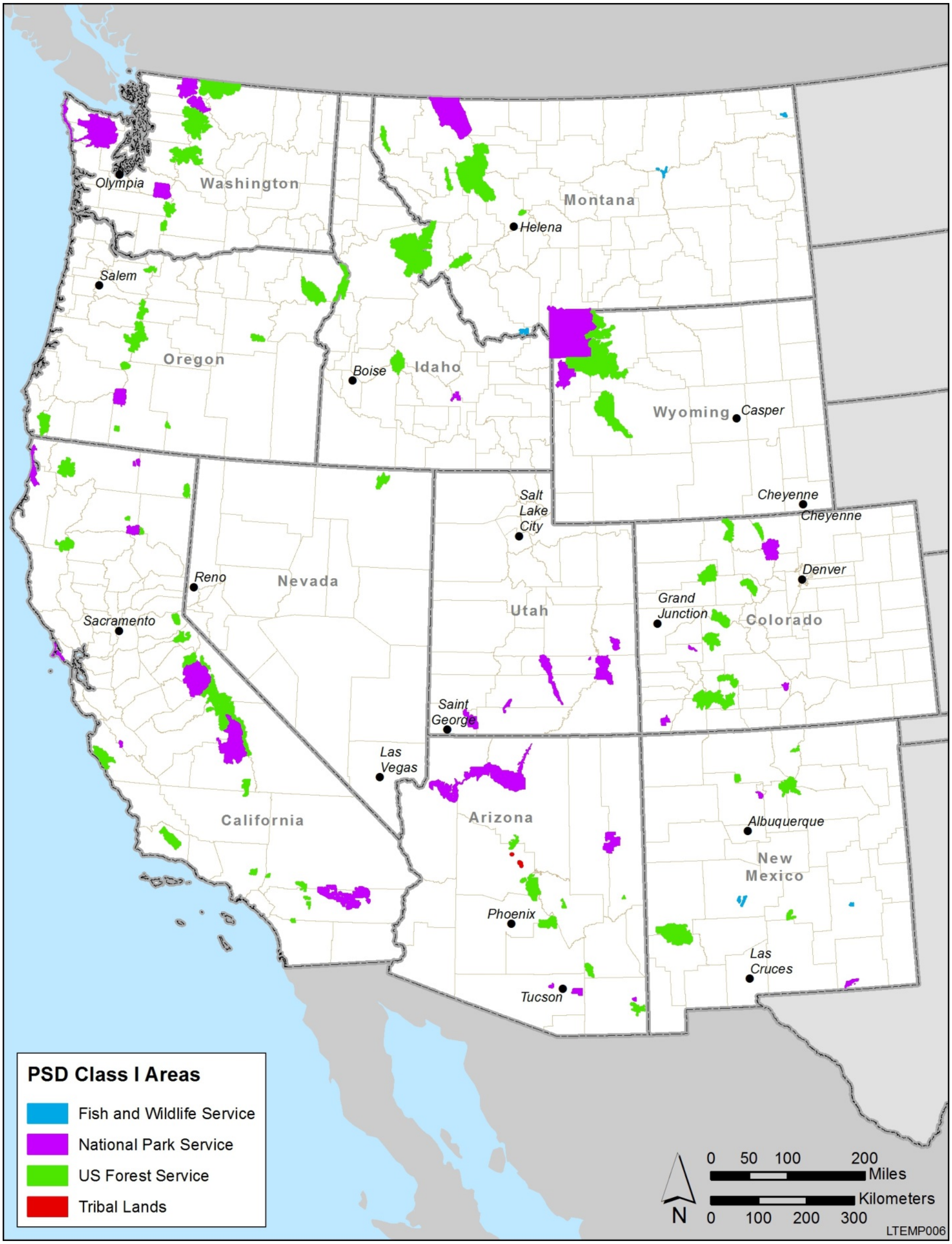

FIGURE 3.15-2 PSD Class I Areas in the 11-State Affected Area (Source: EPA 2013b)

TABLE 3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010, over the 11-State Affected Area within the Western Interconnection

	Annual Emissions (10^3 tons; million metric tons for CO_2e)[a]						
State	CO	NO_x	VOCs	$PM_{2.5}$	PM_{10}	SO_2	CO_2e[b]
Arizona	2,357	251	508	178	405	77	116.6
California	3,674	736	836	208	475	36	453.1
Colorado	1,340	282	500	103	332	57	129.3
Idaho	1,111	98	258	116	431	14	39.6
Montana	1,321	119	342	141	437	29	38.5
Nevada	509	99	87	37	169	13	58.1
New Mexico	1,392	208	440	180	916	30	77.5
Oregon	2,285	161	495	183	372	30	74.7
Utah	595	185	241	39	184	28	75.7
Washington	1,648	278	307	92	249	30	103.0
Wyoming	1,106	196	296	130	483	80	60.3
11-State Total	17,338	2,614	4,311	1,407	4,454	425	1,226.4

[a] CO = carbon monoxide; CO_2e = carbon dioxide equivalent; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter with an aerodynamic diameter of ≤2.5 μm; PM_{10} = particulate matter with an aerodynamic diameter of ≤10 μm; SO_2 = sulfur dioxide; and VOC = volatile organic compound.

[b] Total gross emissions on the consumption basis. To convert from metric ton to ton, multiply by 1.1023.

Sources: ADEQ (2006b); ARB (2014); Bailie et al. (2006), Bailie, Roe, et al. (2007); Bailie, Strait, et al. (2007); CCS (2007); EPA (2013a); NDEP (2008); ODEQ, ODOE, and ODOT (2013); Roe et al. (2007); Strait et al. (2007, 2008).

for Montana are the lowest at 38.5 MMt (42.4 million tons) CO_2e. Wyoming also produces a relatively large amount of CO_2e, but about one-third of the state's CO_2e emissions result from the production of electricity that is exported out of state. Total emissions from the 11-state area are about 1,226.4 MMt (1,351.9 million tons) CO_2e. This equates to about 18.0% of total GHG emissions in the United States during 2010, at 6,810.3 MMt (7,507.0 million tons) CO_2e (EPA 2013c).

3.16 CLIMATE CHANGE

Climate change may affect resources that are also affected by LTEMP alternatives. As explained in the air quality discussion (Section 3.15), changes in operations at Glen Canyon Dam have the potential to alter emissions from other sources of electricity, sources that can produce more GHGs than hydroelectric power. Glen Canyon dam reduces CO_2 emissions by about 1.4 to 3.5 MMt (1.5–3.9 million tons) in an average year (EPA 2014a; Reclamation 2015), which equates to about 0.11 to 0.29% of 11-state total emission. Climate change is also predicted to affect climate and hydrology in the region, which could affect resources in the project area.

As discussed above, dam operations can affect air quality, including the concentration of GHGs in the atmosphere. GHGs are transparent to incoming short-wave radiation from the sun but opaque to outgoing long-wave (infrared) radiation from the earth's surface. The net effect over time is a trapping of absorbed radiation and a tendency to warm the earth's atmosphere, which together constitute the "greenhouse effect." The principal GHGs that enter the atmosphere due to human activities, including fossil fuel power generation, include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Some GHGs such as CO_2, CH_4, and N_2O occur naturally and are emitted to the atmosphere through natural processes as well.

In the arid/semiarid western states, climate change is already having serious consequences on the region's scarce water supplies; this particularly applies to the snow that makes up most of the region's precipitation and that, when melted, provides 70% of its water. To date, decreases in snowpack, less snowfall, earlier snowmelt, more winter rain events, increased peak winter flows, and reduced summer flows have been documented (Saunders et al. 2008). Another potential effect of climate change is that more dust will be produced as vegetative cover decreases and as soils become dry (Mormon 2010). It is widely understood that impurities in snow, such as dust or soot, decrease snow albedo[15] and enhance solar radiation absorption and melt rates. Dust may shorten snow-cover duration by as much as a month (Painter et al. 2007). Earlier spring snowmelt and higher spring/summer temperatures have broad implications with regard to water resources in southwestern states that are already strapped for water, especially during the summer when peak demand is higher, and these factors also lead to increased numbers of forest fires (USGCRP 2014). It is likely that most dust on snowpack at high mountains is coming both from nearby lands where soil-disturbing activity has made the land susceptible to wind erosion and dust from the deserts of Colorado Plateau along with prevailing westerlies, and to dust from other southwestern deserts to some extent. Activities such as exploration and development of energy resources, offroad vehicle use, agriculture, and grazing serve to destabilize soils, making them more susceptible to wind erosion (Belnap et al. 2009).

In December 2012, Reclamation and agencies representing the seven Colorado River Basin States completed the Colorado River Basin Water Supply and Demand Study (Reclamation 2012e). The purpose of the Study was to define future imbalances in water supply and demand in the Basin through the year 2060, and to develop and analyze options and strategies to resolve those imbalances. The study used several different scenarios for both supply and demand to capture a range in potential future conditions. The supply conditions included the downscaled general circulation model (GCM) projected trends and variability (downscaled GCM) scenario. This scenario was developed as one plausible projection of the future based on recent studies of future changes in climate variability and climate trends, and their influence on streamflow and Basin water supply, which indicate that the climate will continue to warm, and

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[15] The fraction of solar radiation reflected from an object or surface, often expressed as a percentage.

that there will be corresponding changes in regional precipitation and temperature trends beyond what has occurred historically. Comparing the median of the water supply projections against the median of the water demand projections, the long-term projected imbalance in future supply and demand is about 3.2 million ac-ft by 2060 (Figure 3.16-1).

Another key Reclamation document that provides information regarding climate change is the 2011 SECURE Water Act Report (Reclamation 2011e). It identifies climate challenges the Colorado River Basin could likely face:

- On average, Colorado River Basin temperature is projected to increase by 5 to 6°F during the 21st century, with slightly larger increases projected in the upper Colorado Basin.
- Precipitation is projected to increase by 2.1% in the upper basin while declining by 1.6% in the lower basin by 2050.
- Mean annual runoff is projected to decrease by 3.5 to 8.5% by 2050.
- Warmer conditions will likely transition snowfall to rainfall, producing more December to March runoff and less April to July runoff.

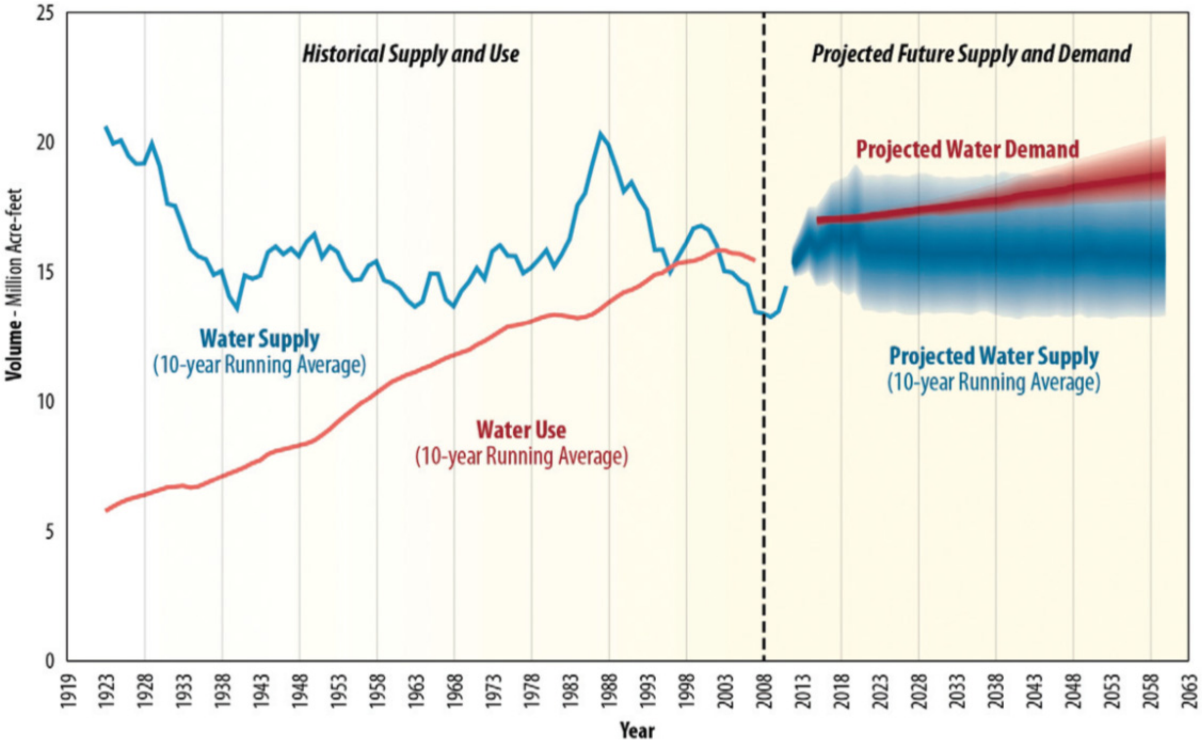

FIGURE 3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water Supply and Demand (medians of projections are indicated by the darker shading) (Source: Reclamation 2012e)

Historical and projected climate changes have potential impacts for the basin:

- Spring and early summer runoff reductions could translate to a drop in water supply for meeting irrigation demands, resulting in lower reservoir levels, which adversely impact energy production from hydropower operations at the Glen Canyon Dam.

- Increased winter runoff may require infrastructure modification or flood control rule changes to preserve flood protection, which could further reduce warm-season water supplies.

- Warmer conditions might cause changes in fisheries habitat, shifts in species geographic ranges, increased water demands for instream ecosystems and thermoelectric power production, increased power demands for municipal uses (including cooling), and increased likelihood of invasive species infestations. Endangered species issues might be exacerbated.

The extent to which climate change could affect future water supply is considered in the hydrology modeling for the proposed action and all alternatives. See Section 3.2.1 for an explanation of the methodology for hydrology modeling.

Although no studies specifically evaluate the potential effects of climate change on Lake Powell or the Colorado River between Lake Powell and Lake Mead, decreases in Lake Powell elevation and corresponding increases in temperatures of water releases from Glen Canyon Dam and in water temperature of the Colorado River downstream (as well as to tributaries of the Colorado River) are important potential effects of climate change on the project area. Projections of future supply and demand in the basin indicate that inflows into Lake Powell may decrease, and the effect of climate change is likely to exacerbate this effect (Reclamation 2012e). Climate-induced changes in inflow, evaporation, and evapotranspiration all have the potential to influence water quality. For example, increased temperatures will increase metabolic rates of aquatic biota, increasing the demand for nutrients and oxygen, and potentially changing the quality of habitat for various organisms (Wrona et al. 2006; Heino et al. 2009; Woodward et al. 2010). Increases in the water temperature of the Colorado River mainstem and its tributaries in the Grand Canyon due to climate change could expand the distribution of warmwater-adapted nonnative fishes (Eaton and Scheller 1996; Rahel and Olden 2008), which can prey on and compete with native fishes such as endangered humpback chub or disadvantaged coldwater nonnative species. Climate-change-driven warmer water temperatures across the contiguous United States are predicted to expand the distribution of existing aquatic nonnative species by providing 31% more suitable habitat for aquatic nonnative species, based upon studies that compared the thermal tolerances of 57 fish species with predictions made from climate change temperature models (Mohseni et al. 2003). Climate change also may facilitate expansion of nonnative parasites such as Asian tapeworm (Rahel et al. 2008), another threat to native fishes such as humpback chub. Cold water temperatures in the mainstem Colorado River in Marble and Grand Canyons have so far prevented these warmwater fishes and parasites from expanding their distribution in the project area. Warmer climate trends could result in warmer overall water temperatures, increasing the prevalence of these species and threating native fish populations.

Climate change effects on Lake Powell's elevation could also affect the amount of electric energy produced by the Glen Canyon Dam Powerplant over the study period, as well as the electric capacity of the Glen Canyon Dam. The hydraulic head (water pressure) on the turbines in the Glen Canyon Dam Powerplant is directly proportional to the elevation in Lake Powell. Thus, when Lake Powell's elevation drops, the amount of hydropower generated by a given release volume also decreases. Ultimately, if Lake Powell drops low enough, no power can be produced at Glen Canyon Dam (at a Lake Powell elevation of 3,490 ft).

In addition to water temperature, other aspects of water quality are also affected by Lake Powell's elevation. Dissolved oxygen concentrations in the tailwater are usually slightly below saturation but have not dropped to concentrations low enough to affect the aquatic ecosystem in the Grand Canyon. However, climate-change driven decreases in the elevation of Lake Powell could increase the chances of water that is low in DO being released from Glen Canyon Dam (Vernieu et al. 2005). Low DO in the tailwater could adversely affect the rainbow trout fishery in Glen Canyon. Similarly, an increase in water temperatures of the Colorado River driven by climate change could cause low levels of DO in Lake Mead that could adversely affect native and nonnative fish (Tietjen 2014).

Climate change could have mixed effects on sediment supply and retention in the Colorado River in the project area. For example, reduced precipitation under climate change could lower sediment input from tributaries to the mainstem of the Colorado River. In addition, higher variability in flows under climate change may require higher flows in equalization years, which could lead to a large erosive effect. Conversely, lower average flows in the Colorado River could positively affect overall sediment retention.

4 ENVIRONMENTAL CONSEQUENCES

Environmental effects are analyzed for resources that could be affected by the proposed action, to adopt and implement an LTEMP for Glen Canyon Dam over the next 20 years. The affected resources are described in Chapter 3. Affected natural resources include water, sediment, aquatic ecology, vegetation, wildlife, special status species, and air quality. Affected socioeconomic resources include cultural resources, visual resources, recreational resources, wilderness, park management and operations, hydropower, regional socioeconomics, resources of importance to Indian Tribes, and environmental justice.

Six action alternatives are compared to the No Action Alternative (Alternative A), which describes how the dam is currently operated. Operations under Alternative A employ a release pattern established in the 1996 Record of Decision (ROD) (Reclamation 1996) associated with the 1995 EIS on operations of Glen Canyon Dam (Reclamation 1995). This operational release pattern, referred to as Modified Low Fluctuating Flows (MLFFs), moderated the releases relative to operations practiced in the 1960s through 1980s. As described in Chapter 2, Alternative A also includes various practices and operational decisions that have been established since the 1996 ROD.

The effects of alternatives result primarily from the patterns of water release from Glen Canyon Dam that are characteristic of each alternative. Monthly, daily, and hourly release rates directly and primarily affect flows and sediment distribution in the river channel and corridor, as well as intraannual water levels in Lake Powell and Lake Mead. These primary effects drive secondary effects on aquatic and terrestrial resources, historic properties, Tribal resources and values, and recreational resources. Hydropower generation and capacity are additional primary effects of release patterns, particularly the ability to adjust releases in response to changes in the demand for electric power. Alternatives also include non-flow actions such as mechanical trout removal and vegetation treatments, which would be undertaken as part of the alternative.

In the following sections, the effects of the alternatives are presented for each resource. Discussions begin with an identification of the resource issues being analyzed and a description of the indicators that are evaluated to assess the related issues. The analysis methodology is presented next, describing both the quantitative and qualitative methods used to assess effects. A summary of effects follows, focusing on the general effects of various flow conditions on resource indicators. An alternative-specific analysis is then presented wherein the effects of the various alternatives are presented individually and compared. Finally, in Section 4.17, an analysis is presented of the cumulative impacts of the alternatives on resources in combination with other past, present, and reasonably foreseeable future actions.

4.1 OVERALL ANALYSIS AND ASSESSMENT APPROACH

Operational characteristics and experimental actions of each alternative are likely to affect resources in different ways. These environmental effects were modeled using historically observed resource responses to flow conditions and relationships derived from experimental results obtained since dam operations were last reviewed in 1995. Information sources used for this analysis included a large quantity of observational and research data collected since the start of dam operations and resulting from research programs originating under the Glen Canyon Adaptive Management Program (GCDAMP) established under the 1996 ROD and carried out by the Grand Canyon Monitoring and Research Center (GCMRC) and other researchers. The geographic region of interest and the topics and issues analyzed as determined from project scoping are described in Section 1.5.

The quantitative analyses in this chapter employed an integrated multiple-resource modeling framework that incorporated a series of linked models that explicitly account for the effects of dam operations and the linkages among resources. The discussion of effects by resource acknowledges these linkages under a common conceptual model. This conceptual model is central to the construction of the LTEMP alternatives as described in Chapter 2. The modeling approach used for this Environmental Impact Statement (EIS) is presented in technical appendices provided in this EIS.

Responses of resources to operations and non-flow actions were predicted using linked models (e.g., reservoir operations model, hydropower operations models, sand budget model, and others, as depicted in Figure 4-1). The magnitude of effects was estimated using quantifiable metrics for indicators of the condition of a resource. The environmental effects of alternatives are compared quantitatively whenever possible, on the basis of the estimated effect on resource condition as measured by a set of resource metrics (see Appendix B for details); these quantitative predictions are supported when possible by published observations and findings. Note that the models used here are mainly intended to allow for relative comparisons among alternatives and not necessarily to be predicitive.

The Department of the Interior (DOI) considered an adaptive management approach when developing its models. This included, but was not limited to, developing models for use in a Structured Decision Analysis (see Appendix C for a full description). Because several of the alternatives use a condition or information-dependent approach to experimentation that would adapt to new information gathered as the alternative is implemented (e.g., Alternatives B, C, D, and E), we developed a set of "long-term strategies" that represented possible ways the alternative might be implemented if uncertainties were resolved. With this approach, we established versions of these alternatives (the long-term strategies) that implemented subsets of the proposed experiments being considered in the alternative. Because there are many possible combinations of experiments within any alternative, we chose sets that would be representative of certain conditions related to uncertainties; there were 19 of these long-term strategies (Table 4.1-1). For example, if under Alternative D the effect of trout on humpback chub was determined to be more important than temperature, and trout management flows (TMFs) proved to be effective at controlling trout numbers, a long-term strategy that included spring and fall high-flow experiments (HFEs) and TMFs would be implemented. Under this scenario, there would be no need for low summer flows to warm water for chub. Long-term strategy D4 represents this scenario. A benefit of the long-term strategies approach is that it allowed for analysis of the combinations of various alternative-specific condition-dependent flow and non-flow actions that would occur if uncertainties were resolved through experimentation and learning. Thus, each long-term strategy represented a possible future implementation of actions

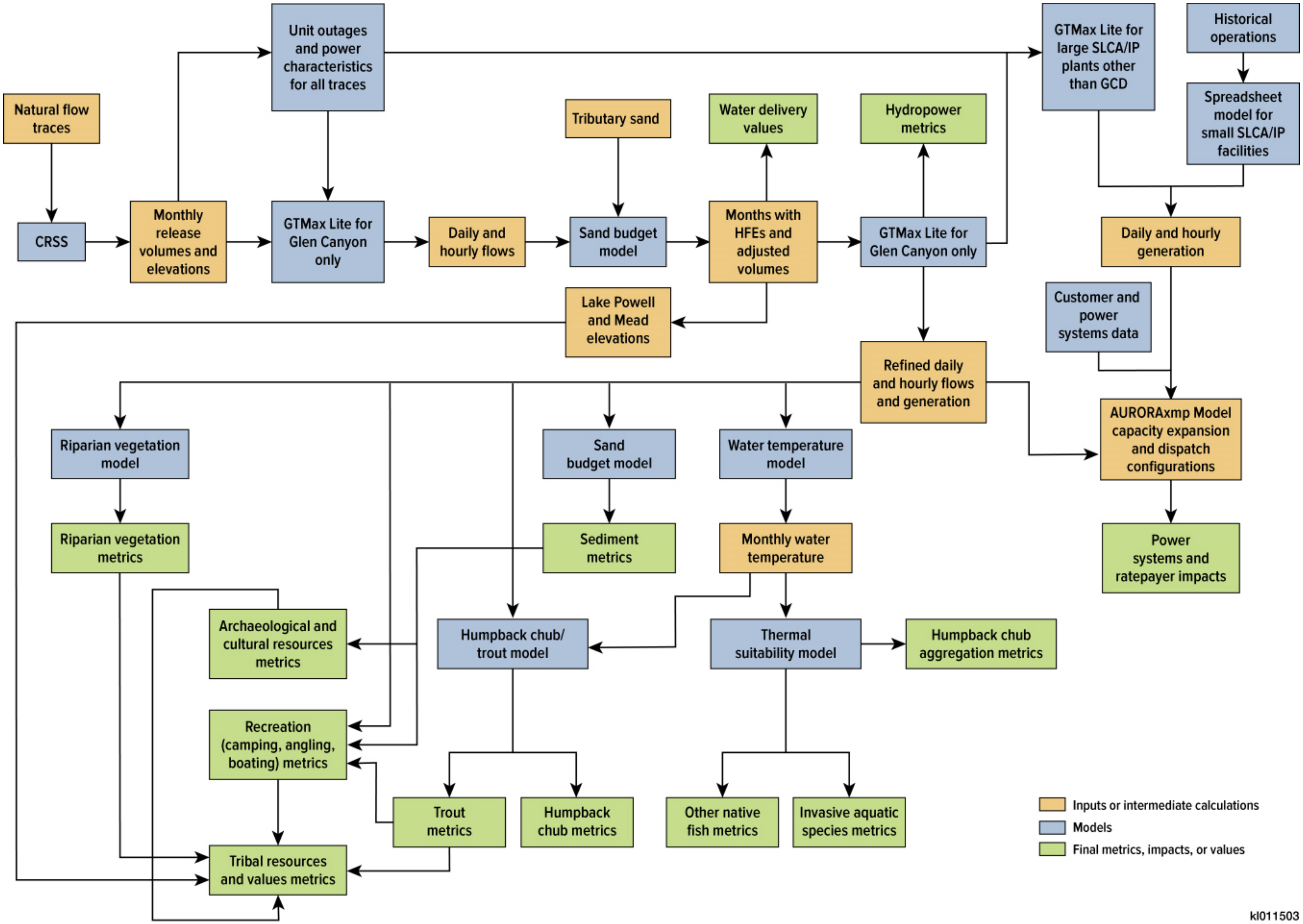

FIGURE 4-1 Integrated Multiple-Resource Modeling Framework Showing Inputs, Intermediate Calculations, and Output

TABLE 4.1-1 Experimental Elements Included in Long-Term Strategies Associated with Each LTEMP Alternative (Letters depict alternative, numbers depict long-term strategy.)

	Alternative and Associated Long-Term Strategy[a]																		
Experimental Element	A	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F	G
Spring HFE	Y[b]	Y[c]	Y[c]	Y	Y	N	N	Y[d]	Y[d]	Y[d]	Y[d]	Y[e]	Y[e]	N	N	N	N	Y	Y
Fall HFE	Y[b]	Y[c]	Y[c]	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y
Spring proactive HFE	N	N	N	Y[f]	Y[f]	N	N	Y[f]	Y[f]	Y[f]	Y[f]	N	N	N	N	N	N	N	Y[f]
Extended-duration HFE	N	N	N	Y[g]	Y[g]	N	Y[g]	Y[h]	Y[h]	Y[h]	Y[h]	N	N	N	N	N	N	N	Y[i]
Load-following curtailment (steady flows)	N	N	N	Y[j]	Y[j]	N	Y[j]	N[k]	N[k]	N[k]	N[k]	Y[l]	Y[l]	N	Y[l]	N	N	N	N
Low summer flows	N	N	N	N	Y[m]	N	N	Y[n]	Y[n]	Y[n]	N	N	Y[o]	N	N	Y[o]	N	N	N
Macroinvertebrate production flows	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
Mechanical trout removal	Y[b]	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	Y
Trout management flows	N	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N	Y
Hydropower improvement flows	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

[a] Y = element included; N = element not included. Long-term strategies that include the element are shaded gray.

[b] Activity ends after 2020.

[c] Not to exceed one HFE (spring and fall) every other year.

[d] Not to occur in first 2 years of LTEMP. Would not be conducted in the same water year as an extended-duration fall HFE.

[e] Not to occur in first 10 years of LTEMP.

[f] Triggered in years with annual release volume ≥10 maf. Not implemented in the same water year as a sediment-triggered spring HFE or an extended-duration fall HFE.

[g] Volume limited to that of a 96-hr, 45,000-cfs release.

[h] Fall only, limited to four HFEs up to 250 hr if sediment will support, first implementation limited to 192 hr.

[i] Spring and fall HFEs, no limit in number, up to 336 hr long if sediment will support.

[j] Before and after spring and fall HFEs.

[k] This experiment was dropped from Alternative D in the Final EIS based on comments on the Draft EIS from stakeholders and GCMRC. GCMRC scientists indicated that the effects of this experiment could be too small to measure with current monitoring methods. The potential importance of load-following curtailment is also expected to be small because, under current practice, the volume of released water and fluctuations are reduced in the remaining days of the month in which HFEs occur to compensate for the large volume released during the HFE.

[l] Before fall HFEs only.

[m] Target 13°C.

[n] Target 14°C, second 10 years only.

[o] Target 16°C, second 10 years only.

under the overall constraints of each alternative. Not all possible combinations were evaluated; instead, a set of long-term strategies that represented the expected range of combined flow and non-flow actions were chosen for analysis. These combinations allowed for examination of the effects of specific experiments when they were included in a long-term strategy. This approach is described more fully in Appendix C.

To facilitate comparisons of alternatives in the text, we chose a single-long-term strategy for each alternative—A, B1, C1, D4, E1, F, and G. Long-term strategies C1, D4, and E1 were chosen because they included a comparable set of experimental elements (spring and fall HFEs and TMFs). Long-term strategy B1 was chosen because it did not include hydropower improvement flows, and was thus comparable to other long-term strategies. The analytical results for the full suite of long-term strategies enabled a determination of the effects of experiments, and these effects are described in the individual resource sections of this chapter. The quantitative results for all 19 long-term strategies are presented in Appendix C and the resource-specific Appendices E, F, G, H, I, and J.

For those resource metrics that could be modeled quantitatively, a range of potential hydrologic conditions and sediment conditions were modeled for a 20-year period that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell inflow scenarios (known as hydrology traces) for the 20-year LTEMP were sampled from the 105-year historic record (water years 1906 to 2010) using the Index Sequential Method and selecting every fifth sequence of 20 years. Using this approach, the first 20-year period considered was 1906–1925, the second was 1911–1930, and so forth. As the start of traces reach the end of the historic record, the years needed to complete a 20-year period are obtained by wrapping back to the beginning of the historical record. For instance, the trace beginning in 1996 consists of the years 1996–2010 and 1906–1910, in that order. This method produced 21 hydrology traces for analysis that represented a range of possible traces from dry to wet. Although these hydrology traces represent the range of hydrologic conditions that occurred during the period of record, they may not fully capture the driest years that could occur with climate change (see Section 4.17).

In addition to these 21 hydrology traces, three 20-year sequences of sediment inputs from the Paria River sediment record (water years 1964 to 2013) were analyzed that represented low (water years 1982 to 2001), medium (water year 1996 to 1965), and high (water years 2012 to 1981) amounts of sediment. In combination, the 21 hydrology traces and three sediment traces resulted in an analysis that considered 63 possible hydrology-sediment conditions.

Models depicted in Figure 4-1 were used to generate resource metric values for each of the alternatives under the 63 hydrology-sediment combinations. The values generated represent a range of possible outcomes that in many cases were graphed using box-and-whisker plots (Figure 4-2), which show the full distribution of values obtained as characterized by the minimum, maximum, mean (average of all values), median (50% of the values are less than this value), 25th percentile (25% of the values are less than this value), and 75th percentile (75% of the values are less than this value).

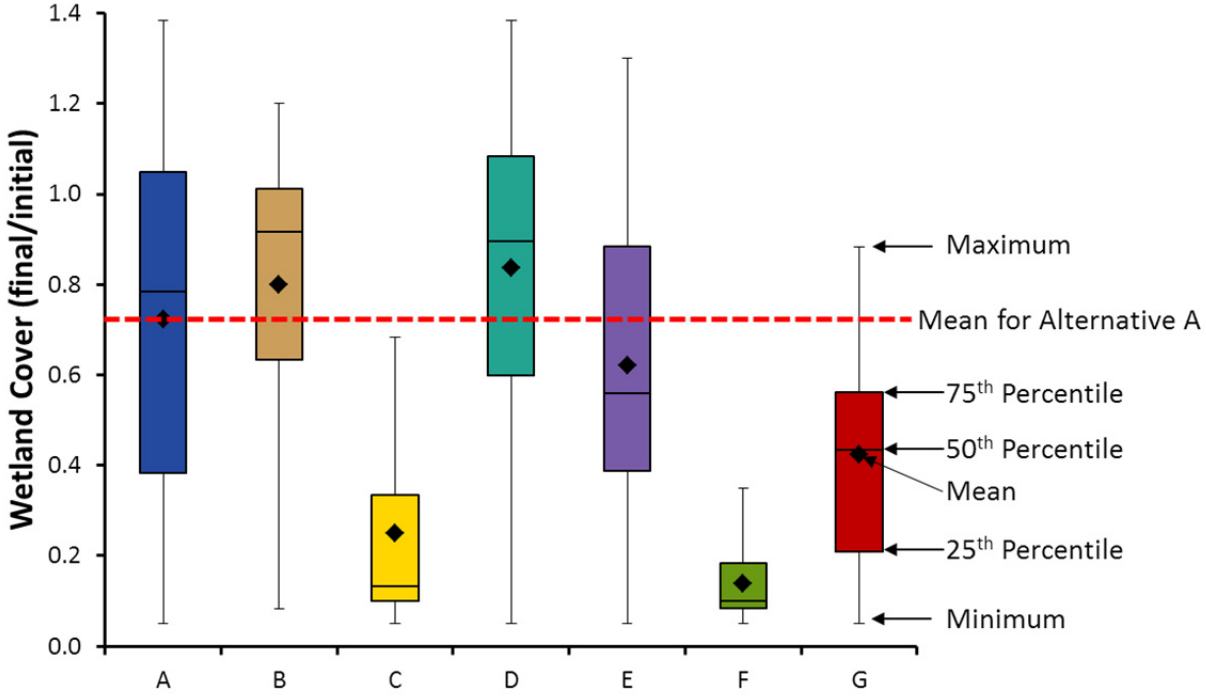

FIGURE 4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric Values

Some resources or environmental attributes do not lend themselves to quantification because there are insufficient data or understanding to support development of a model. In these cases, the assessment presented in this chapter includes qualitative assessments of the likely impacts on these resources and attributes. Qualitative analysis was particularly important for effects related to personal and cultural values, as well as for an assessment of impacts on resources not directly affected by river flow. In all cases, multiple lines of evidence, including consultation with subject matter experts, were used to assess impacts on resources.

The analytical results presented in this chapter represent, in part, the results of integrated multiple-resource modeling completed in March 2015. After this modeling was completed, several adjustments were made to specific operational and experimental characteristics of Alternative D (the preferred alternative) based on discussions with Cooperating Agencies and stakeholders. These adjustments included (1) an increase in release volume in August with corresponding decreases in May and June (in an 8.23-maf year, the increase was 50 kaf in August, i.e., from 750 to 800 kaf; and a reduction of 25 kaf each in May and June; these changes were applied proportionally to monthly volumes in drier and wetter years); (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE—previously, it lasted from the HFE until December 1, but after the adjustment it lasts from the HFE until the end of the month in which the HFE occurred; and (4) a prohibition on sediment-triggered spring HFEs in the same water year as an extended-duration fall HFE. Adjustments made to Alternative D after the Draft EIS (DEIS) was published, and based on comments received from Cooperating Agencies and stakeholders on the DEIS, included (1) elimination of load-following curtailment after a fall HFE and (2) a prohibition on proactive spring HFEs in the same water year as an extended-duration fall HFE. The description of Alternative D provided in Section 2.2.4 represents the final version of the alternative that resulted from these changes.

Once the adjustments to Alternative D were made, analyzing them using multiple-resource modeling would have taken many months and incurred significant additional cost. Therefore, instead of performing multiple-resource modeling on the effects of these adjustments, the joint-leads chose to perform streamlined modeling using the screening tool (described in Section 2.1) and additional analysis to assess the magnitude and direction of these effects of the adjustments. As described in the following paragraphs, for most resources, these adjustments to Alternative D are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D. However, the streamlined analysis did show that the adjustments could result in some changes to the expected impacts on sediment and hydropower resources, and that for all resources but hydropower these changes would not affect the relative performance of Alternative D compared to other alternatives. Because the adjustments to Alternative D would not change Alternative D's relative performance for most resources, and the changes to hydropower impacts would be reductions in impact rather than increases, the agencies chose not to perform additional multiple-resource modeling. In addition to presenting the original multiple-resource modeling results, the results of the streamlined modeling evaluating the effects of these adjustments on sediment and hydropower are presented in Sections 4.3.3.4 and 4.13.3.4, respectively. Because, for resources other than sediment and hydropower, these adjustments are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D, the only quantitative analysis results presented in those sections of the EIS are those from the original multiple-resource modeling.

Modeling of the effects of load-following curtailment determined that this experimental treatment would have a very small effect on sediment resources, the intended beneficiary of this treatment. Modeling indicated that there would be a very small effect of load-following curtailment on the sand load index (a measure of sandbar-building potential; see Section 4.3.1 for a description) immediately following the treatment, but that any difference in this index between HFEs with and without load-following curtailment would disappear by the end of the water year (see Section E.3.5 of Appendix E). In addition, the treatment had a small effect on sediment mass balance (estimated conservation of about 9,000 metric tons, or 0.04%, of the average annual sediment input from the Paria River). This decrease would represent a 0.6% decrease in the sand mass balance index (a measure of the amount of sand retained in the Marble Canyon reach of the Colorado River; see Section 4.3.1 for a description of the index). GCMRC scientists indicated that the effects of this experiment could be too small to measure with current monitoring methods. The potential importance of load-following curtailment is also expected to be small because, under current practice, the volume of released water and fluctuations are reduced in the remaining days of the month in which HFEs occur to compensate for the large volume released during the HFE.

Since load-following curtailment has an adverse effect on hydropower generation, the value of generation without this experiment is expected to be slightly higher than with the experiment (i.e., impacts on hydropower would be reduced under the revised Alternative D). Streamlined modeling using the screening tool indicated that, without load-following curtailment, there would be a reduction in the NPV of the cost of Alternative D of about $4.0 million. This adjustment would have no effect on hydropower capacity because August release volume, from which capacity is estimated, would be unaffected. The impacts of this change on all other resources are expected to be negligible.

Prohibition of sediment-triggered and proactive spring HFEs after extended-duration fall HFEs is expected to have relatively little effect on the impact of Alternative D because of the relatively low probability of these combinations being triggered in any water year. Without the prohibition, an average of 5.2 sediment-triggered spring HFEs and 1.6 proactive spring HFEs would occur over the 20-year LTEMP period. With the prohibition, there would be 4.1 sediment-triggered spring HFEs (1.1 fewer) and 1.4 proactive spring HFEs (0.2 fewer). In total, this prohibition on spring HFEs after an extended-duration fall HFE would result in an average of 1.3 fewer HFEs over the LTEMP period, and a potential slight reduction in sandbar building potential (sand load index) and slight increase in sand mass balance. The slight reduction in the number of HFEs would reduce the cost of the alternative on hydropower generation by about $2.1 million in a 20-year period, based on the average cost of an HFE of $1.64 million presented in Section 4.13.2.3. The impacts of this change on all other resources are expected to be negligible.

The change in August volume in an 8.23-maf year from 750 to 800 kaf, with proportional adjustments in drier and wetter years, is expected to have relatively minor effects and potentially undetectable changes on most downstream resources because the change in mean daily flow would be small (about an 800 cfs increase in August and a 400 cfs decrease in May and June, when volumes would be reduced by 25 kaf in each month to offset the increase in August volume), and the adjusted August monthly volume is below the 900 kaf of Alternative A (the no-action alternative). This adjustment in monthly volumes could, however, affect the alternative’s impacts on hydropower and sediment resources. As estimated using the screening tool, the adjustments in monthly volume are expected to reduce the NPV of the cost of generation and capacity by about $5.3 million and $27.6 million, respectively, over the 20-year period. The effect on sediment would be a slight increase in sediment transport (about 1.2%), resulting in a lower SLI and a lower sand mass balance index. For resources other than sediment and hydropower, these adjustments are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D.

Note that the technical appendices of the EIS describe the original modeling results developed before Alternative D adjustments were made, and do not discuss the effects these adjustments would have on anticipated impacts.

4.2 WATER RESOURCES

This section presents an analysis of impacts on water resources of the Colorado River between Glen Canyon Dam and Lake Mead, and in Lake Powell and Lake Mead. This section is organized into two broad topics—hydrology and water quality. The hydrology section encompasses those topics related to the pattern and volume of monthly, daily, and hourly releases from Lake Powell. The water quality section relates to non-flow characteristics of the water, including temperature, salinity, dissolved oxygen (DO), turbidity, nutrients, metals, organics, and bacteria and other pathogens. Analysis methods, a summary of impacts, and alternative-specific impacts are presented in Sections 4.2.1, 4.2.2, and 4.2.3, respectively.

Issue: How do the alternatives affect water resources in the project area?

Impact Indicators:

- Lake Powell releases (annual, monthly, daily, and hourly)
- Lake Powell and Lake Mead reservoir elevations
- Lake Powell annual Operating Tier and Lake Mead operating conditions
- Monthly, hourly, and daily patterns in Colorado River flows downstream of Glen Canyon Dam

The water resources objective was developed to ensure the LTEMP does not affect fulfillment of water delivery obligations to the communities and agriculture that depend on Colorado River water and remains consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria (LROC) for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

A primary aspect of reservoir operations that potentially affects water resources is related to the monthly distribution of the Lake Powell annual release volume and its resulting impact on reservoir elevations, operating tiers, and annual release volumes. Changes to monthly release volumes have the potential to, in critical time periods, affect reservoir elevations for operating tier determinations, which could in rare circumstances affect annual release volumes. The impact analysis for water resources reflects the 20-year LTEMP period, which, for modeling purposes, was from October 1, 2013, to September 30, 2033. Analyses of the alternatives have been performed in order to avoid changes in annual volume releases and thereby ensure operations are consistent with the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines.

Quantitative analysis of the effects of reservoir operations was performed using Reclamation's official basin-wide long-term planning model, Colorado River Simulation System (CRSS). Model results provide a range of potential future system conditions such as reservoir releases and storage, as well as operating tiers for Lake Powell and Lake Mead.

4.2.1 Analysis Methods

4.2.1.1 Hydrology

Annual and Monthly Operations

Modeling of the Colorado River system was conducted to determine whether there were potential effects of LTEMP alternatives on annual and monthly operations on Colorado River system conditions (e.g., reservoir elevations, reservoir releases, and river flows) as compared to Alternative A (the No Action Alternative). Due to uncertainties associated with future inflows into the system, multiple simulations were performed for each alternative in order to quantify the uncertainties in future conditions, and the modeling results are expressed in probabilistic terms.

Future Colorado River system conditions under the LTEMP alternatives were simulated using CRSS. The model framework used for this process is the commercial software RiverWare™ (Zagona et al. 2001), a generalized river basin modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation, the Tennessee Valley Authority, and the U.S. Army Corps of Engineers. CRSS was originally developed by Reclamation in the early 1970s, was converted to RiverWare™ in 1996, and has been used as Reclamation's primary Colorado River Basin–wide planning model since that time. Previous studies that used CRSS include the 1996 Glen Canyon Operations EIS (Reclamation 1995), the 2007 Interim Guidelines EIS (Reclamation 2007a), and the Colorado River Basin Water Supply and Demand Study, referred to as the Basin Study (Reclamation 2012a).

CRSS simulates the operation of 12 major reservoirs on the Colorado River system and provides information regarding the projected future state of the system on a monthly basis; the model simulates the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and diversions to and return flows from water users throughout the system. The basis of the simulation is a mass balance (or water budget) calculation that accounts for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, and evaporation), and water moving through the system (e.g., either stored in reservoirs or flowing in river reaches). Further explanation of the model is provided in Appendix D. CRSS was used to project the future conditions of the Colorado River system for the 20-year LTEMP period, which for modeling purposes was water years 2013 through 2033.[1]

The input data for the model includes monthly natural inflows; various physical process parameters such as the evaporation rates for each reservoir; initial reservoir conditions on

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[1] The water year is defined as October 1 through September 30 of the following calendar year.

January 1, 2013[2]; and the future projected diversion and depletion schedules for entities in the seven Basin States (Appendix D) and for Mexico. These future schedules are based on demand and depletion projections prepared and submitted by the Basin States for the Basin Study, and assume the Current Projected demand scenario (Schedule A) from the Basin Study. For purposes of this EIS, depletions (or water consumptive uses) are defined as diversions from the river less return flows.

For each alternative, the rules of operation of the Colorado River mainstem reservoirs, including Lake Powell and Lake Mead, were developed as input to the model. These sets of operating rules describe how water would be released and delivered under various hydrologic conditions. In the modeling of all alternatives, the operations of Lake Powell and Lake Mead are assumed to revert back in 2027 to the assumptions used to represent the No Action Alternative in the 2007 Interim Guidelines. Because CRSS is a monthly model, reservoir operations at sub-monthly intervals (e.g., daily release fluctuations, ramp rates, HFEs, and TMFs) were not explicitly modeled in CRSS, but they were modeled using other modeling software. Further explanation of the operating rules for each alternative is provided in Section 2.2.

Long-term planning models, such as CRSS, are typically used to project future river and reservoir conditions over a period of years or decades into the future. There are numerous inputs to, and assumptions made by, these models. As the period of analysis increases (for this EIS the analysis period is 20 years), the uncertainty in those inputs and assumptions also increases. Consequently, these models are not used to predict future river and reservoir conditions, but rather to project the range of possible effects. When analyzing the potential hydrologic impacts from operational alternatives, most inputs, as well as other key modeling assumptions, are held constant for each alternative to isolate the differences due to each alternative. In this manner, the analyses for each alternative may be compared, and thus a relative comparison of the impacts of alternatives can be made.

Uncertainties in CRSS output are due to assumptions in input, including parameterization of physical processes such as reservoir evaporation and bank storage, the future diversion and depletion schedules for the entities throughout the Colorado River Basin, and the future inflows into the system. In addition, much of the input data are derived from actual measurements that have uncertainties associated with them. For example, natural flows (i.e., those flows that would occur in the absence of dams, reservoirs, diversions, and withdrawals) are partially based on data acquired from streamflow gages, which, when calibrated properly, have uncertainties of about 5 to 10%. Although these data are generally the best available, all of these uncertainties limit the absolute accuracy of the model. However, by holding most inputs constant, the relative comparisons among modeled conditions are still valid.

Despite the differences in the LTEMP alternatives, the future conditions of the Colorado River system (e.g., future Lake Mead and Lake Powell elevations) are most sensitive to future

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[2] Initial reservoir conditions as of January 1, 2013, were used in conjunction with the CRSS modeling, which started at the beginning of water year 2013 (October 1, 2012). However, since the hydrology is not intended to be predictive of conditions in a given year, but rather to show how the alternatives vary in response to a variety of hydrological conditions, the actual starting year does not affect the relative comparison of alternatives.

inflows. Observations over the period of historical record (1906 through 2010) show that inflow into the system has been highly variable from year to year and over decades. Because it is impossible to predict the actual future inflows for the next 20 years, a range of possible future inflows are analyzed and used to quantify the probability of occurrences of particular events (e.g., higher or lower reservoir elevations). This technique, performed for the hydrologic analysis presented here, involves multiple simulations for each alternative, one for each future hydrologic sequence.

The future hydrology used as input to the model consisted of samples taken from the historical record of natural flow in the river system over the 105-year period from 1906 through 2010 from 29 individual inflow points (or nodes) on the system. The locations of the inflow nodes are described in Appendix D.

Typically, CRSS is run with the full suite of available natural flow traces created using a resampling technique known as the Indexed Sequential Method (ISM) (Ouarda et al. 1997). Using the ISM on a 105-year record (1906–2010) results in 105 inflow traces (i.e., plausible inflow sequences). For this EIS, every fifth trace from the 105 natural flow traces was selected, resulting in 21 traces that are considered representative of the full period of record (Appendix D). For the climate change analysis described in Section 4.26, CRSS was run with 112 natural flow traces developed from downscaled general circulation model projected hydrologic traces (Reclamation 2011f).

As shown in Figure 4-1, a full set of resource models was used to analyze resource impacts, and CRSS output served as input for most of these models. Reservoir operations under each alternative were explicitly modeled in CRSS. Each alternative was modeled in CRSS with 21 different potential hydrology scenarios to account for uncertainty in future hydrologic conditions. Comparisons between alternatives are made on these 21 simulations per alternative. The interquartile range indicates that 50% of the estimated values fall within this range, 25% of the values are below this range, and 25% are above this range.

Daily and Hourly Operations

Monthly volumes under each alternative, as predicted by CRSS and described in the previous section, were used as input to determine daily and hourly patterns of releases using GTMax-Lite, a program developed by Argonne National Laboratory for hydropower modeling (see Appendix K for technical information and analysis related to the hydropower systems modeling). Within each month, this program determines the pattern of daily and hourly releases that would maximize hydropower value based on CRSS-predicted monthly volume, reservoir elevation, hourly electricity market prices, and the operational constraints of each alternative, including maximum and minimum flows, ramping rates, and allowable daily range.

Hourly flows were generated using the GTmax-Lite model for the 20-year LTEMP period under each of the 21 hydrology scenarios and three sediment scenarios that were analyzed for each alternative. This resulted in 63 unique 20-year simulations for each alternative. Daily and hourly flow data were statistically analyzed to generate values of mean daily flow, mean daily change (maximum flow minus the minimum flow for each day), and monthly volume for each alternative, and to show the variation in these variables over the range of scenarios analyzed.

4.2.1.2 Water Quality

This section describes the methods used to determine the potential effects on water quality associated with the LTEMP alternatives. Details of the methodologies used are presented in Appendix F of this EIS.

Using the hydrologic output from the CRSS RiverWare^{TM} model (see Section 4.2.1.1), the CE-QUAL-W2 model (Cole and Wells 2003) was used to simulate water temperatures of Lake Powell (including dam releases).

Temperature exerts a major influence on biological and chemical processes. Aquatic organisms have preferred temperature ranges that influence their abundance and distribution. DO concentrations are generally lower, while salinity levels, nutrient, and pathogen concentrations are higher in warmer water. Temperature modeling for the Colorado River below Glen Canyon Dam was performed using the method described in Wright, Anderson et al. (2008). This model computes gains and losses of heat as water moves down the river. In general, predicted downstream temperatures are driven by the release temperature from Glen Canyon Dam, equilibrium water temperature (i.e., the temperature the water would eventually reach if it did not flow; dependent on air temperature, direct insolation, wind patterns, and evaporation), temperature and volumes of tributary inflows, and a heat exchange coefficient, which are all complex functions of environmental conditions (Walters et al. 2000).

The salinity module of the CRSS RiverWare^{TM} model was used to analyze changes in salinity concentration for Colorado River reaches from Lake Powell to Imperial Dam, which is located downstream of Hoover Dam and Lake Mead. The Salinity Control Act sets numerical criteria for salinity concentrations on the Colorado River. Monthly salinity estimates were aggregated to annual values because the salinity criteria/standards set for Colorado are based on flow-weighted average annual salinity (mg/L). Other water quality parameters (e.g., DO, turbidity, nutrients, metals, organics, and bacteria/pathogens) were not modeled quantitatively. Qualitative assessments of these parameters in the Colorado River between Lake Powell and Lake Mead were based on previous scientific studies and historical data, including published research, related EISs, and Environmental Assessments (EAs).

Detailed modeling for Lake Mead was conducted by the Southern Nevada Water Authority because of concerns related to the potential effects of LTEMP alternatives on the quality of municipal water supplies. The temperature modeling was performed using the model described in Flow Science (2011). The Lake Mead Model (LMM) uses the ELCOM (Estuary, Lake and Coastal Ocean Model) code to simulate hydrology and conservative constituents, and CAEDYM (Computational Aquatic Ecosystem Dynamics Model) code for simulating biogeochemical processes.

Ten 2-year model scenarios were chosen to represent a subset of LTEMP alternatives that could result in important water quality impacts (Tietjen 2015). The goal of modeling was to indicate the possibility of effects that could occur. The 10 selected scenarios were separated into three general elevation-based scenarios. The first scenario covers water years 2014–2015, which have higher relative reservoir surface elevations (1,080–1,110 ft AMSL), and models hydrology trace 8, sediment trace 1, and Alternatives A, E (represented by two long-term strategies, E1 and E5), and F. The second scenario looks at water years 2018–2019, with lower relative reservoir surface elevations (1,040–1,060 ft AMSL), and models hydrology trace 11, sediment trace 1, and Alternatives A, E (long-term strategy E1), and F. The third scenario covers water years 2019–2020, which displays a high starting reservoir surface elevation that decreases significantly (1,125–1,070 ft AMSL), and hydrology trace 18, sediment trace 1, and models Alternatives A, E (long-term strategy E6), and F.

4.2.2 Summary of Impacts

The overall impacts of the seven LTEMP alternatives on the hydrology and water quality of Lake Powell, the Colorado River below Glen Canyon Dam, and Lake Mead are presented in this section and summarized in Table 4.2-1. A discussion of alternative-specific impacts is provided in Section 4.2.3. Impacts on seeps and springs are discussed in Section 4.9.1.2.

4.2.2.1 Hydrology

Impacts on annual, monthly, daily, and hourly reservoir releases, elevations, and annual operating tiers, as well as consistency with water delivery considerations, are discussed in the subsections below.

Lake Powell Operating Tier and Annual Release Volume

The Lake Powell annual operating tier and annual release volume are driven by hydrological conditions in a given year, and by the LROC as currently implemented through the 2007 Interim Guidelines. The modeled Lake Powell annual release volumes range from 7.0 maf to 19.2 maf, with a median value of 8.23 maf, across all years, traces, and alternatives.

The Lake Powell annual release volume is driven by the annual operating tier, which is set based on projections of end-of-calendar-year and end-of-water-year elevations in Lake Powell and Lake Mead. Under the 2007 Interim Guidelines, Lake Powell operates under four operating tiers. Each operating tier has a specific logic for determining the required annual release within that tier. Depending on the operating tier, the annual release is either a set volume determined at the beginning of the water year, or a variable volume based on projected and actual inflows and resulting Lake Powell and Lake Mead elevations and storages. LTEMP actions will be implemented consistent with these operations.

TABLE 4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water Quality

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology							
Overall summary of impacts	No change from current condition in reservoir elevations, annual operating tiers, monthly release volumes, mean daily flows, or mean daily changes in flow (up to 8,000 cfs).	Compared to Alternative A, no change from current condition related to reservoir elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months (up to 12,000 cfs). Hydropower improvement flows would cause even greater mean daily flow changes.	Compared to Alternative A, some change from current condition related to reservoir elevations (<2 ft difference for each reservoir at end of Dec.), annual operating tiers (2.1% of years), monthly release volumes and mean daily flows (lower in Aug. and Sept.); lower mean daily changes in flow in all months (up to 6,200 cfs).	Compared to Alternative A, some change from current condition related to reservoir elevations (0.2 ft difference for Lake Powell, no difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months (up to 8,000 cfs).	Compared to Alternative A, negligible change from current condition related to reservoir elevations (0.3 ft difference for Lake Powell, 0.1 ft for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows (lower in Aug. and Sept.); higher mean daily changes in flow in all but Sept. and Oct. (up to 9,600 cfs).	Compared to Alternative A, some change from current condition related to reservoir elevations (about 3 ft difference for each reservoir at end of Dec.) and annual operating tiers (2.1% of years); large changes in monthly release volumes and mean daily flows (high volume in May and Jun., low in other months); steady flows throughout the year.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.4 ft difference for Lake Powell, 1.4 ft for Lake Mead at end of Dec.) and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year.
Lake Powell and Lake Mead Reservoir elevations	No change from current condition; reservoir elevations vary significantly with inflow hydrology; Lake Powell and Lake Mead operate at times within the full range of operating elevations.	Same as Alternative A for end-of-Dec. elevations for Lake Powell and Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 1.5 ft higher at Lake Powell and 0.6 ft lower at Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 0.2 ft higher at Lake Powell but the same at Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 0.3 ft higher at Lake Powell and 0.1 ft lower at Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 3.2 ft higher at Lake Powell and 2.9 ft lower at Lake Mead, the largest difference of all alternatives.	Compared to Alternative A, end-of-Dec. elevations would be on average 0.4 ft lower at Lake Powell and 1.4 ft higher at Lake Mead.

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Lake Powell annual operating tier	No change from current condition; Alternative A would operate at times within each of the four operating tiers during the period 2013–2026 and at times within both operating tiers during the period 2027–2033.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Compared to Alternative A, would operate in a different tier an average of 0.7% of years; there would be the same frequency of operating tiers, but different timing during the analysis period.

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Monthly release volume	No change from current condition; monthly volumes would be highest in Dec., Jan., Jun., Jul., Aug., and Sept. (670,000 to 1,500,000 ac-ft; 570,000 to 1,200,000 ac-ft in other months).	Same as Alternative A.	Compared to Alternative A, higher volumes in Feb. through May (by 82,000 to 157,000 ac-ft); lower in Aug., Sept., and Oct. (by 111,000 to 200,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 43,000 to 98,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 60,000 to 127,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 45,000 to 128,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 30,000 to 242,000 ac-ft).	Compared to Alternative A, much higher volume in Apr., May, and Jun. (by 439,000 to 651,000 ac-ft); much lower in Dec., Jan., Jul., Aug, and Sept. (by 214,000 to 433,00 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Mar., and Apr. (by 71,000 to 286,000 ac-ft); lower in Dec., Jan., Jul., and Aug. (by 139,000 to 196,000 ac-ft).
Mean daily flow	No change from current condition; mean daily flows are highest in Dec., Jan., Jun., Jul., Aug., and Sept. (11,200 to 24,600 cfs; 9,400 to 14,400 cfs in other months).	Same as Alternative A.	Compared to Alternative A, higher mean daily flow in Feb. through May (by 1,300 to 2,500 cfs); lower in Aug., Sept., and Oct. (by 1,800 to 3,300 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 3,000 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 1,000 to 2,100 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 2,100 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 500 to 4,000 cfs).	Compared to Alternative A, much higher mean daily flow in Apr. through Jun. (by 7,400 to 10,600 cfs); much lower in Dec. and Jan. and Jul. through Sept. (by 3,600 to 7,000 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Mar., Apr. (by 1,200 to 4,800 cfs); lower in Dec., Jan., Jul., and Aug. (by 2,300 to 3,200 cfs).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Mean daily change in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs in Dec., Jan., Jun., Jul., Aug., and Sept.; 2,600 to 6,400 cfs in other months.	Compared to Alternative A, mean daily change higher in all months (range about 2,500 to 12,000 cfs).	Compared to Alternative A, mean daily change lower in all months (about 1,300 to 6,200 cfs).	Compared to Alternative A, mean daily change slightly higher in Oct. through Jun., same or less in Jul. through Aug. (range about 2,700 to 7,600 cfs).	Compared to Alternative A, mean daily change higher in all months but Sept. and Oct. (range about 1,100 to 9,600 cfs).	Mean daily change is zero except for ramping up and down from spring and fall HFEs.	Mean daily change is zero except for ramping up and down from spring and fall HFEs.
Water Quality							
Overall summary of impacts	No change in temperature or other water quality indicators from current conditions.	Compared to Alternative A, negligible differences in temperature or other water quality indicators.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A and the other alternatives, greatest increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.
Water temperature (change from Lees Ferry to Diamond Creek)	No change from current conditions; summer warming would be lowest among alternatives (average 5.6°C).	Same as Alternative A.	Summer warming would be higher than under Alternative A (average 5.8°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be highest among alternatives (average 6.8°C).	Summer warming would be higher than under Alternative A (average 6.2°C).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Water Quality (Cont.)							
Salinity	Negligible change from current condition. Negligible alternative-specific differences (<2.5%) expected because, regardless of operating conditions, salinity would not increase over time or exceed control criteria.						
Turbidity	Negligible change from current condition. No alternative-specific differences expected because potential turbidity increases due to scouring during HFEs are expected to be temporary and any observed fluctuations recover quickly when lower flows return. Effects of operational changes related to tributaries are currently unknown.						
Bacteria and pathogens	No change from current condition.	Compared to Alternative A, slightly lower probability of the occurrence of bacteria and pathogens because of higher within-day fluctuations.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during low summer flow experiments.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during low summer flow experiments.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during low summer flow experiments.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during annual low steady flows.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during year-round steady flows.
Nutrients	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, waters are expected to remain relatively low in nutrients.						
Dissolved oxygen	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, DO concentrations are expected to remain within the accepted healthy range for fish.						
Metals/ radionuclides	Negligible change from current condition. No alternative-specific differences expected because operational changes will not affect metal/radionuclide concentrations. There are no concerns related to these substances because levels do not exceed any enforceable human-health-based standards or guidance values.						
Organic/other contaminants	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, organic and other contaminant concentrations are expected to remain below those considered toxic.						

Modeling incorporated the elevation-based triggers from the 2007 Interim Guidelines through 2026 regarding annual release volumes from Glen Canyon Dam. The selection of the annual operating tier at Lake Powell and Lake Mead and the annual release volumes can, in some instances, be affected by the differing monthly release patterns of the LTEMP alternatives. The differences regarding operating tier selections and annual volumes among alternatives occur only in rare circumstances (see Appendix D for more detail). Two pimary causes contribute to the identified model results showing differences in operating tier or different annual release volumes: (1) October to December release ratio; and (2) differences in equalization releases when maximum release is a constraining factor.

October to December Release Ratio. Alternatives that release proportionally different volume during October through December, relative to the rest of the water year, result in a slightly different end-of-year Lake Powell elevation (and slightly different end-of-year Lake Mead elevation), and can, accordingly in those circumstances, when Lake Powell elevation is projected to be close to an operating tier threshold, result in a different operating tier selection, potentially impacting the implementation of a different operating tier at Lake Powell and Lake Mead, as well as different annual volumes. This effect (a changed operating tier) is projected to occur very infrequently (0 to 2.1 % of years, depending on the alternative) and constituted all occurrences of operating tier differences from Alternative A in this modeling. Alternatives with the same October through December volume as Alternative A (2,000 kaf in an 8.23-maf year) did not result in a different operating tier. Alternatives B, D, and E also have October–December volumes of 2,000 kaf, but Alternatives C, F, and G have October–December volumes of 1,790 kaf, 1,466 kaf, and 2,075 kaf, respectively.

Effects Due to Differences in Equalization Releases when Maximum Release Is a Constraining Factor. Modeling assumptions for equalization operations are needed for a full analysis of monthly and annual operations in this LTEMP EIS. These assumptions are for analytical purposes only and do not, and cannot, modify the Secretary's approach to operations of equalization releases, which are made pursuant to the Colorado River Basin Project Act of 1968. Modeled equalization release volumes can be affected by the annual pattern of monthly volumes. Alternatives that have higher releases earlier in the water year are able to release more water in years when the maximum release through the powerplant becomes a potential limiting factor to equalizing within the water year, which is consistent with the objectives of applicable federal law. A limitation of the current modeling assumptions is that they cannot fully mimic or predict operator judgment or actions to achieve full equalization within the relevant timeframe. Reclamation will continue to operate Glen Canyon Dam to achieve equalization releases in a manner fully consistent with the Law of the River and in consultation with the Colorado River Basin States. As hydrologic conditions change throughout the water year, the annual release volume also shifts. In years when the annual release volume increases throughout the year, it may not be possible to release the entire volume in the remaining months of the water year through the powerplant turbines; thus, some must be released the following water year. Generally, the action alternatives pass more water earlier in the water year (through July) and thus have less potential for annual releases extending beyond the water year than Alternative A (0 to 200 kaf less, depending on the alternative). This can result in different modeled annual volumes, but that difference is made up in the following water year. This effect does not result in different operating tiers.

Monthly Releases

Although annual release volumes would be nearly the same under each of the LTEMP alternatives, the monthly patterning of that annual volume varies significantly among the alternatives. Monthly release patterns for each of the alternatives in years with different annual release volumes are shown in Figure 4.2-1. Monthly releases were shaped for each alternative in an 8.23-maf year and then generally scaled proportionally to the 8.23-maf pattern relative to the annual volume.[3] For example, 763 kaf in January for Alternative D in an 8.23-maf year scaled to 1,104 kaf in January for an 11-maf year. For years when the annual volume reaches the maximum release capacity of Glen Canyon Dam, the monthly distribution of releases became more similar across alternatives (Figure 4.2-1). Monthly release volumes for different annual releases are included in Appendix D.

Monthly releases sometimes would be limited by the minimum or maximum release constraints at Glen Canyon Dam. In low annual volume release years, monthly volumes sometimes would be increased to ensure that the minimum hourly release objective of each alternative could be maintained throughout the month. In high annual release years, monthly volumes sometimes would be decreased because they were capped at the maximum release capacity (45,000 cfs), and the remaining volume was released in the following month(s). See Appendix D for further detail.

Operationally, annual releases and the associated monthly releases are affected by hydrologic uncertainty. In some cases, Lake Powell's annual release target changes throughout the water year because the actual inflow volume is not known until the end of the water year. Reservoir operators utilize inflow forecasts throughout the year to project the expected annual release volume and allocate the monthly releases accordingly in order to make releases consistent with the LROC as currently implemented through the 2007 Interim Guidelines. This effect of hydrologic uncertainty is captured, in part, through a forecasting algorithm in CRSS. However, due to modeling limitations, monthly release patterns under actual operating conditions are likely to differ from the modeling results.

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[3] Note that adjustments to Alternative D made after modeling was completed resulted in a 50-kaf increase in August (changed from 750 kaf to 800 kaf) and a corresponding 25-kaf decrease in both May and June (changed from 657 to 632 kaf and 688 to 663 kaf, respectively) in an 8.23-maf year.

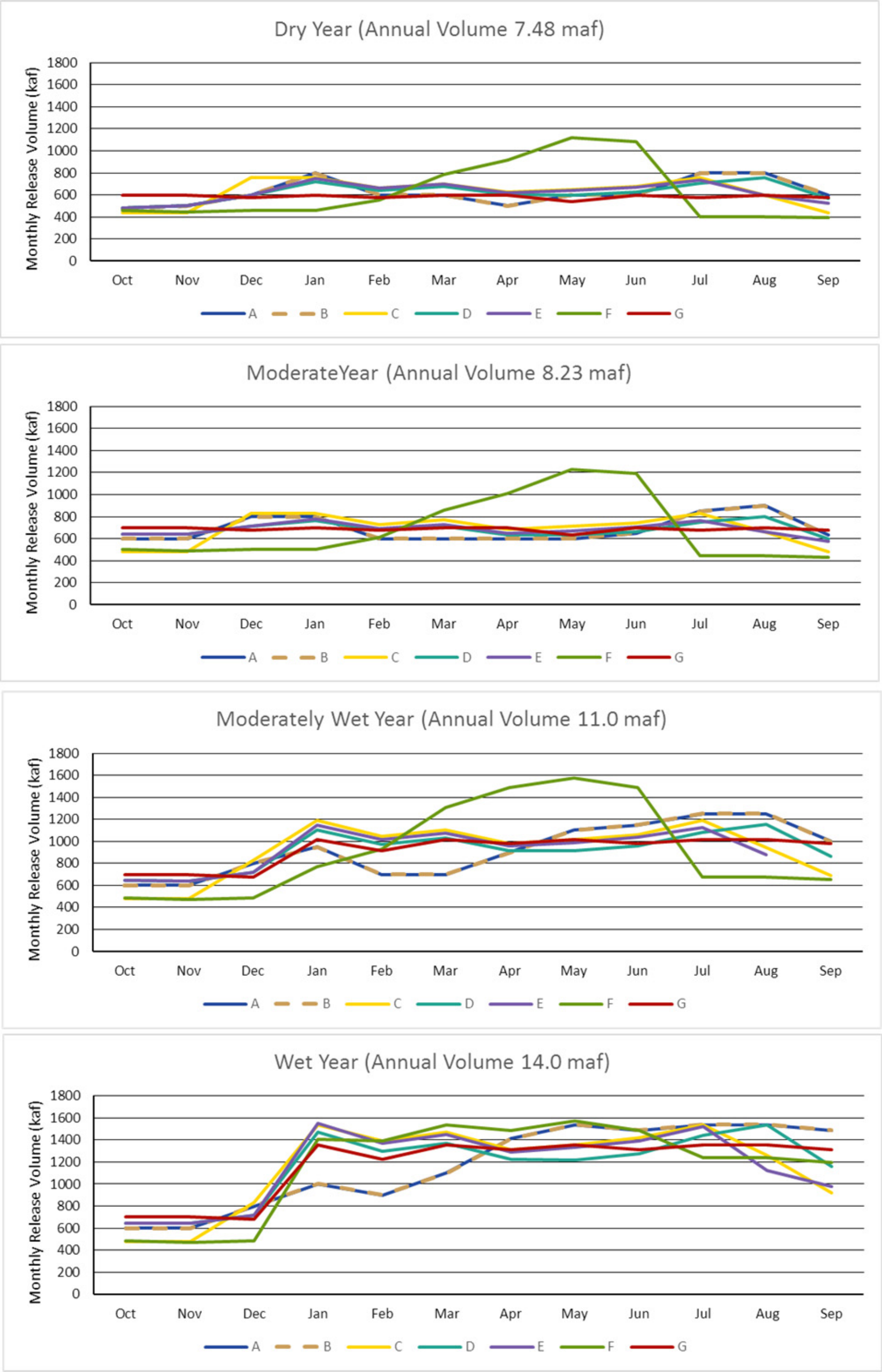

FIGURE 4.2-1 Monthly Releases under Each Alternative in Years with Different Annual Release Volumes

Monthly release volume can also be affected by HFEs. For HFEs that require more water than was already allocated for the given month of the HFE, water is reallocated from later months to ensure the water year release volume remains the same. The monthly reallocation of releases to support a HFE does not affect the Lake Powell operating tier. See Appendix D for further detail.

Monthly releases can also be affected by low summer flows. Low summer flows could be implemented as an experimental component under Alternatives C, D, and E. During years with low summer flows, releases would be lower than typical in July, August, and September, and proportionally higher in May and June, in order to maintain the same annual release volume. Subject to the decision-making process outlined in Section 2.2.4.3, low summer flows may be implemented if three conditions are met: (1) the projected annual release was less than 10 maf; (2) the projected temperature at the confluence with the Little Colorado River in July, August, or September was less than 13°C (Alternatives C and E) or less than 14°C (Alternative D); and (3) switching to the low summer flow pattern resulted in temperatures of at least 13°C (Alternatives C and E) or at least14°C (Alternative D) in those months. For those alternatives with low summer flows, the number of those flows in the 20-year period was estimated to range from zero to four occurrences. Depending on the alternative, the average ranges from 0.7 to 1.8 low summer flows per 20-year run. See Appendix D for further detail.

Mean monthly release volumes averaged over all years within each run are shown in Figure 4.2-2. The variability in these values reflects the effect on operations of natural variability in inflows observed in the historical record. The differences among alternatives in mean monthly release volumes are a function of the monthly volume patterns established in the definition of each alternative (see Chapter 2 for a description of these operational constraints).

Within alternatives, mean monthly volumes would vary the most among the scenarios in the months of June through September (Figure 4.2-2). This pattern of variability is a result of adjustments in operations in the latter half of the water year in response to forecasts that become more certain after June 1. During the first half of the water year, operations tend to be more conservative (less variable) to ensure sufficient water remains for the remainder of the year to meet minimum flows.

Mean monthly volumes under Alternative F are consistently the most different from other alternatives, with volume being lower in December, January, July, August, and September, but higher in April, May, and June (Figure 4.2-2). This monthly pattern is intended to more closely match a natural hydrograph with high spring flows and low summer through winter flows. Other variations among alternatives are less apparent, although Alternatives C and E both target lower August and September volumes to conserve sediment prior to fall HFEs.

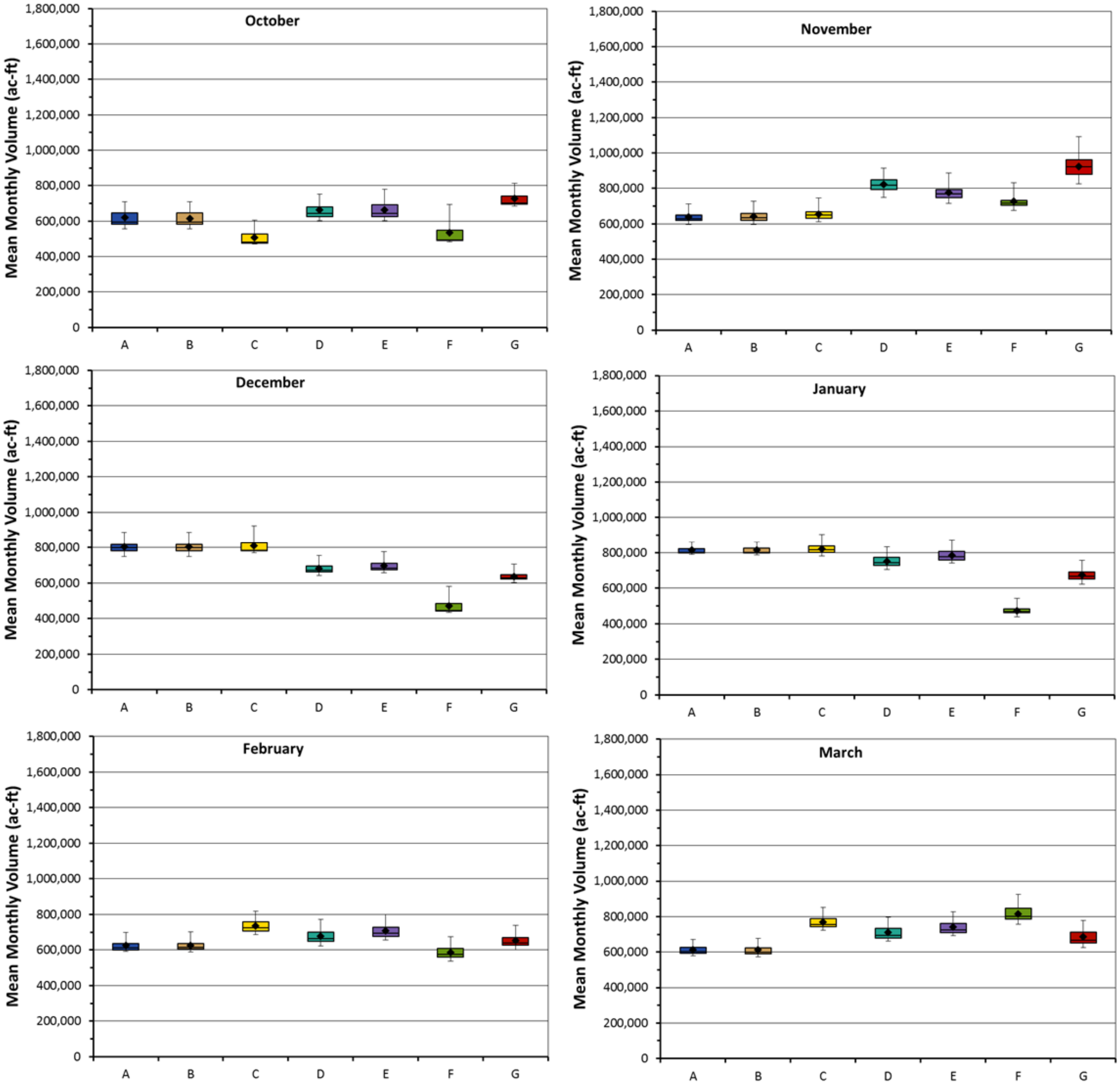

FIGURE 4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

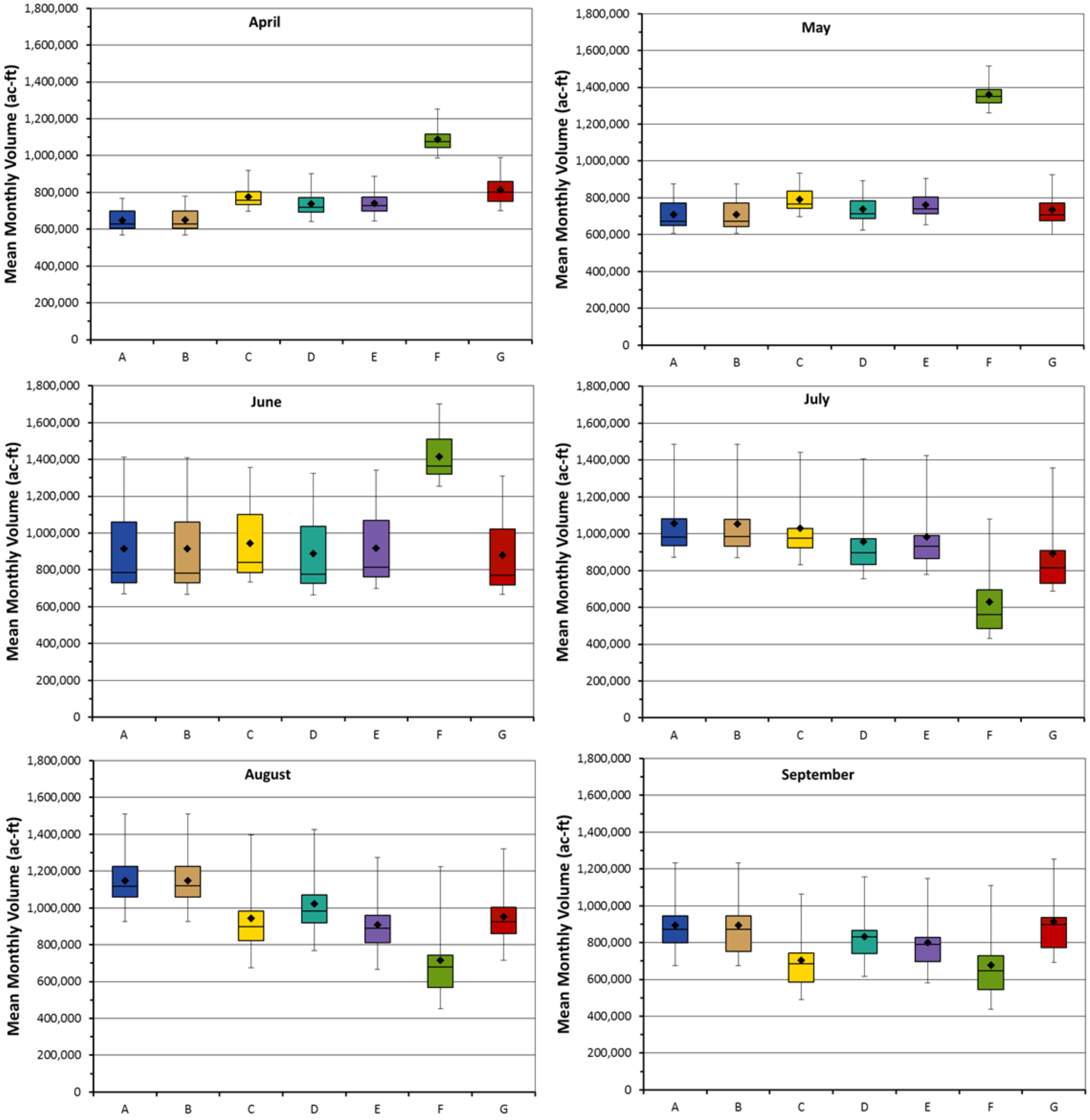

FIGURE 4.2-2 (Cont.)

Daily and Hourly Releases and Ramp Rates

For most alternatives, releases from Glen Canyon Dam fluctuate throughout the day in response to hydropower demand. Releases are generally higher during the day when there is a higher demand for hydropower, and lower during the night when the demand is lower. The fluctuation within a day (i.e., from nighttime low to daytime high) varies by alternative and is typically relative to the monthly release volume. For example, months with a higher release volume typically have a larger daily range of releases. Two alternatives, Alternatives F and G, do not have daily or hourly release fluctuations.

The range of daily releases is further defined by a required minimum release and is alternative specific. The scheduled hourly release rate must be equal to or greater than the prescribed minimum release. The minimum release during the daytime is typically higher than the minimum release during the nighttime.

The peak release in a day is determined by the maximum allowable daily fluctuation, and the daily and monthly release volume. In cases when the required monthly release is very large, the peak daily release could be limited by reservoir outlet works capacity, which is a function of reservoir head. Generally speaking, the maximum possible release without using the spillway was computed as 45,000 cfs. The actual maximum release may be lower, depending on reservoir elevation and the number of available hydropower units.

Ramp rates, the change in release from one hour to the next, are also specific to each alternative (Chapter 2). Ramp rates down vary by alternative; ramp rates up are the same for all alternatives (Chapter 2, Table 2-1). For all alternatives, the ramp rate up is faster than the ramp rate down.

Daily release volumes vary throughout the week relative to hydropower demand. Release volumes are typically larger during weekdays, when the demand for hydropower is higher, and release volumes are lower during the weekends and holidays.

Mean daily flow and mean daily change vary among alternatives, in part due to differences in the monthly volume patterns established for each alternative, but also as a result of operational constraints characteristic of each alternative (see Chapter 2 for a description of these operational constraints) (Figures 4.2-3 and 4.2-4).

Within alternatives, mean daily flows would vary the most among the scenarios in the months of June through September (Figure 4.2-3). This pattern can be attributed to increased variability in monthly volume, as described in the previous section.

Mean daily flows under Alternative F are consistently the most different from other alternatives, with mean daily flows being lower in December, January, July, August, and September, but higher in April, May, and June (Figure 4.2-3). These differences are a result of the monthly release pattern of this alternative, as described in the previous section. Other variations among alternatives are less apparent, although Alternatives C and E both target lower August and September volumes to conserve sediment prior to fall HFEs.

Similar to the pattern discussed above for mean daily flows, mean daily change would vary the most among the scenarios in the months of June through September (Figure 4.2-4). This pattern reflects the variability in monthly volume, which determines the level of amount of daily change allowed under each alternative.

Mean daily change varies among the alternatives, ranging from 0 cfs (in all but the months with HFEs) in the two steady flow alternatives (Alternatives F and G), to up to 12,000 cfs in Alternative B. Of the fluctuating flow alternatives (Alternatives A−E), Alternative C has the lowest mean daily change. Relative to Alternative A, mean daily change

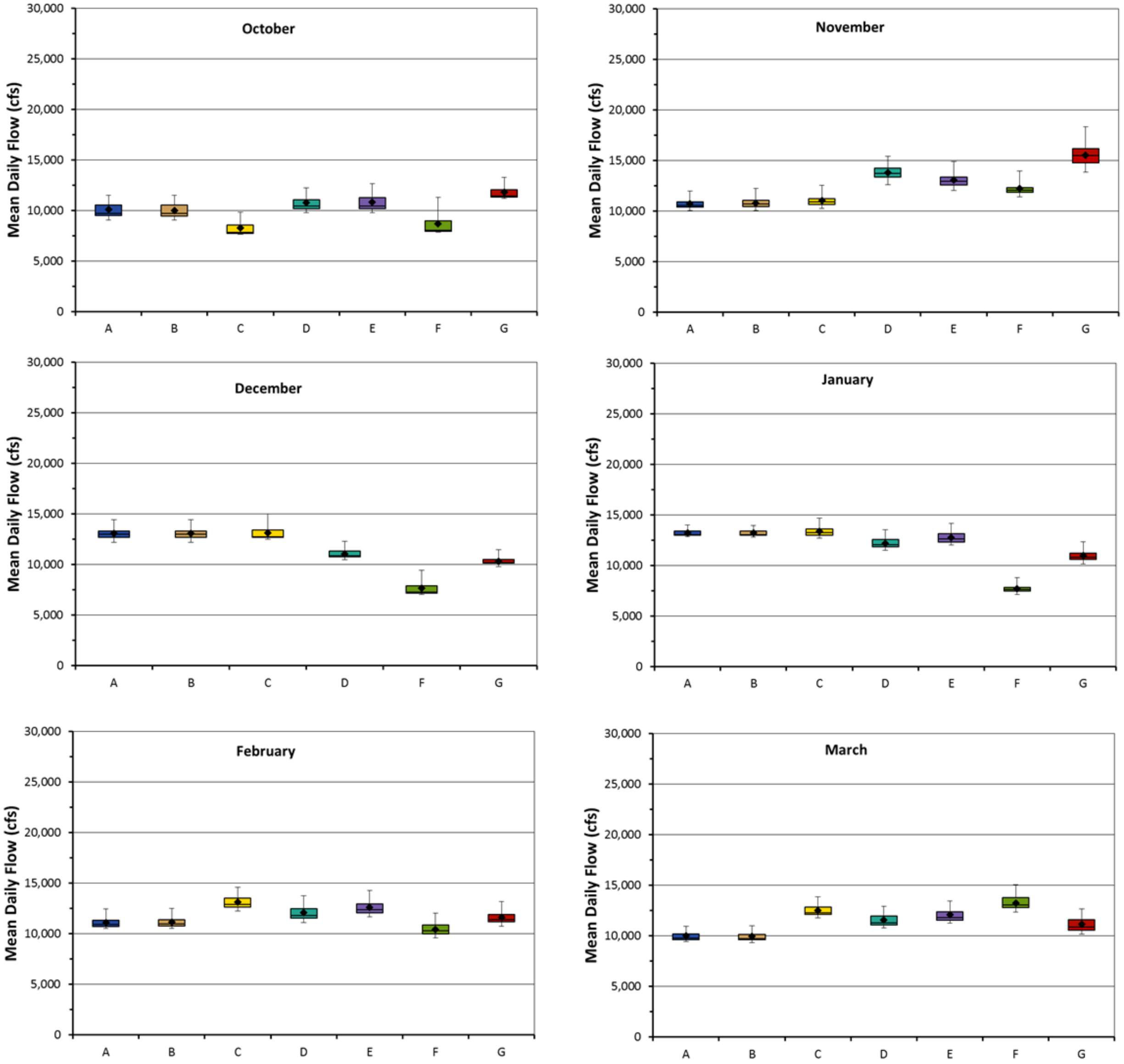

FIGURE 4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

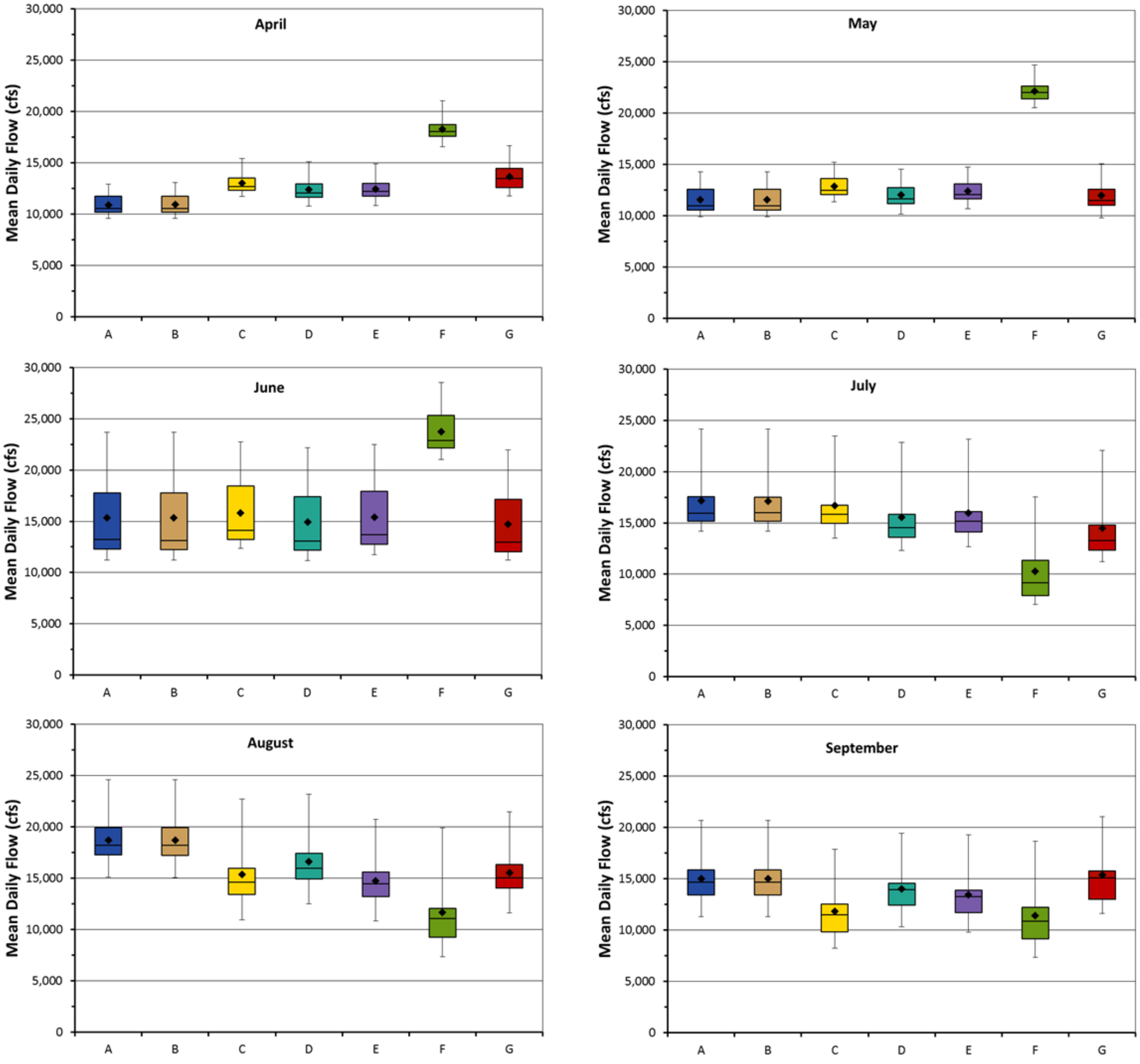

FIGURE 4.2-3 (Cont.)

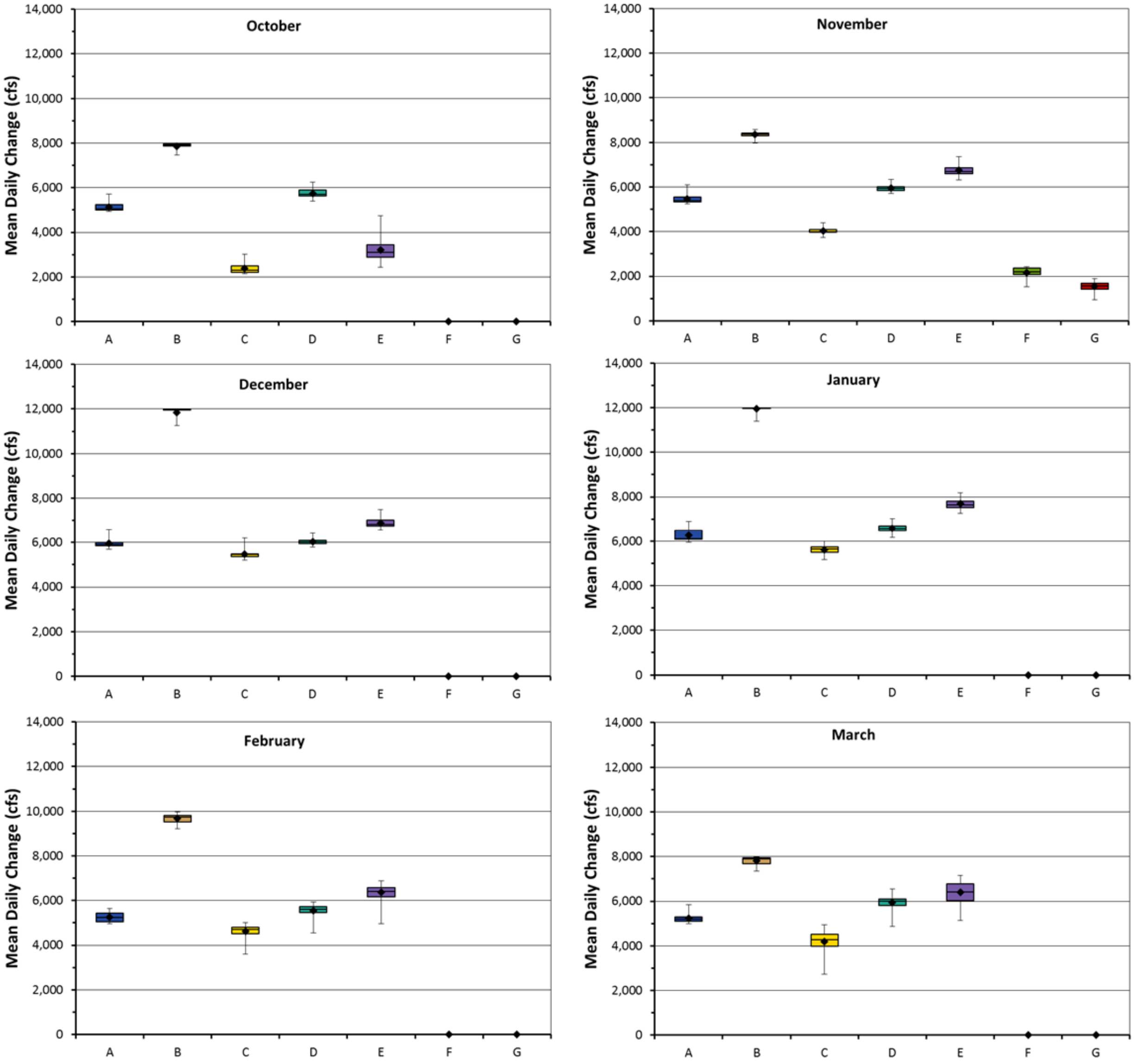

FIGURE 4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

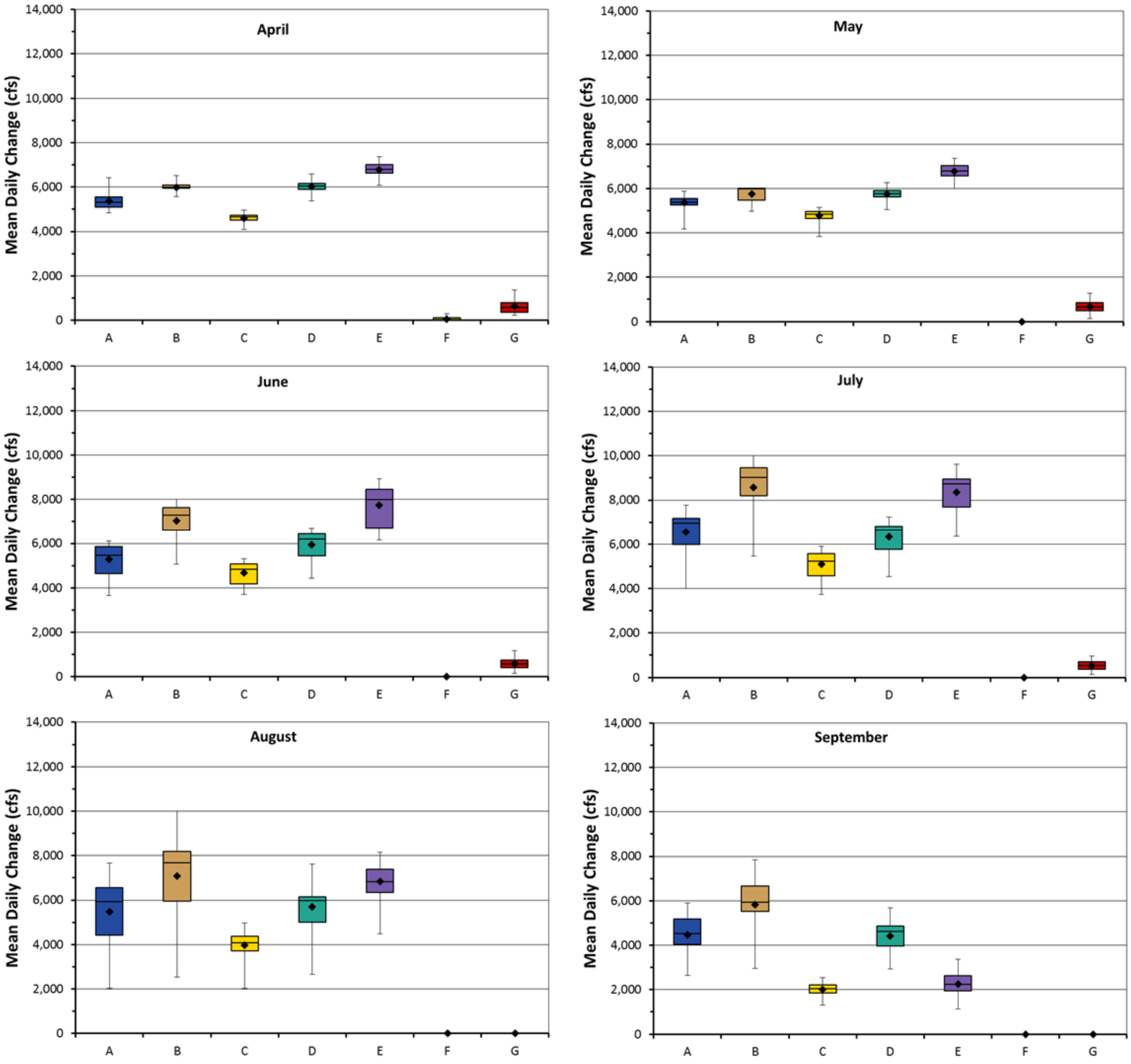

FIGURE 4.2-4 (Cont.)

under Alternative D is most similar; Alternatives C, F, and G are consistently lower; Alternative B is consistently higher; and Alternative E is higher in all months but September and October when load-following curtailment prior to HFEs would occur.

Reservoir Elevations

Lake Powell elevations are affected by potential future hydrology and Glen Canyon Dam operations. Lake Mead elevations are similarly affected by Glen Canyon Dam releases and Hoover Dam operations (including those related to meeting downstream water delivery obligations).

The elevations of Lake Powell and Lake Mead are more affected by annual variation in inflow than by alternative. Figure 4.2-5 presents end-of-calendar-year elevations for Lake Powell and Lake Mead at the 10th, 50th, and 90th percentiles for 21 different hydrology traces and the seven different alternatives. The plots show that uncertainty associated with annual variation in inflow (variation among years) creates a larger range of pool elevations than do the differences within years among alternatives. In addition, differences among alternatives are greater at the 10th and 50th percentiles, corresponding to lower reservoir elevations and drier hydrology. Differences at the 90th percentile, which corresponds to higher reservoir elevations and wetter hydrology, are minimal across all alternatives.

The percentage of traces with Lake Powell falling below 3,490 ft (modeled minimum power pool) and the percentage of traces with Lower Basin shortages are shown in Figure 4.2-6. The probability of these conditions occurring is more affected by annual variation in inflow than by alternative. For Lake Powell elevations, all alternatives show very similar percentages for elevations that are ≤3,490 ft. The percentage of traces ranges between 0 and 5 and remains relatively constant throughout the 20-year period. Typically, alternatives that show differences from Alternative A are due to an alternative releasing more or less water from October through March (the typical low elevation months). Alternatives that release less water in this period will have a lower probability of falling below 3,490 ft (e.g., Alternative F reduces the probability in 2017 and 2032).

For Lower Basin shortages pursuant to the applicable provisions of the LROC as currently implemented through the 2007 Interim Guidelines (i.e., when Lake Mead's elevation is projected to be at or below 1,075 ft on January 1), the percentages are also similar across alternatives, though with slightly more variability than with the Lake Powell minimum power pool. The percentage of traces with Lower Basin shortages generally increases over the 20-year period, ranging from zero in the first years of the period to nearly 62% of traces near the end of the period. The greatest difference across all alternatives is 19% in any given year. The October through December release from Lake Powell is the largest contributing factor in differences between Alternative A and the other alternatives.

Alternatives that release less water in October through December show higher chances of shortages in the Lower Basin (e.g., Alternative F).

Glen Canyon Dam Annual Release

To evaluate potential differences among alternatives related to Glen Canyon Dam annual releases, the following metrics were calculated:

- Frequency of deviation from Alternative A with regard to Lake Powell annual operating tier as specified by the 2007 Interim Guidelines,
- Probability over time of Lake Powell being in each operating tier as specified in the 2007 Interim Guidelines, and
- Frequency and volume of modeled annual release extending beyond the water year.

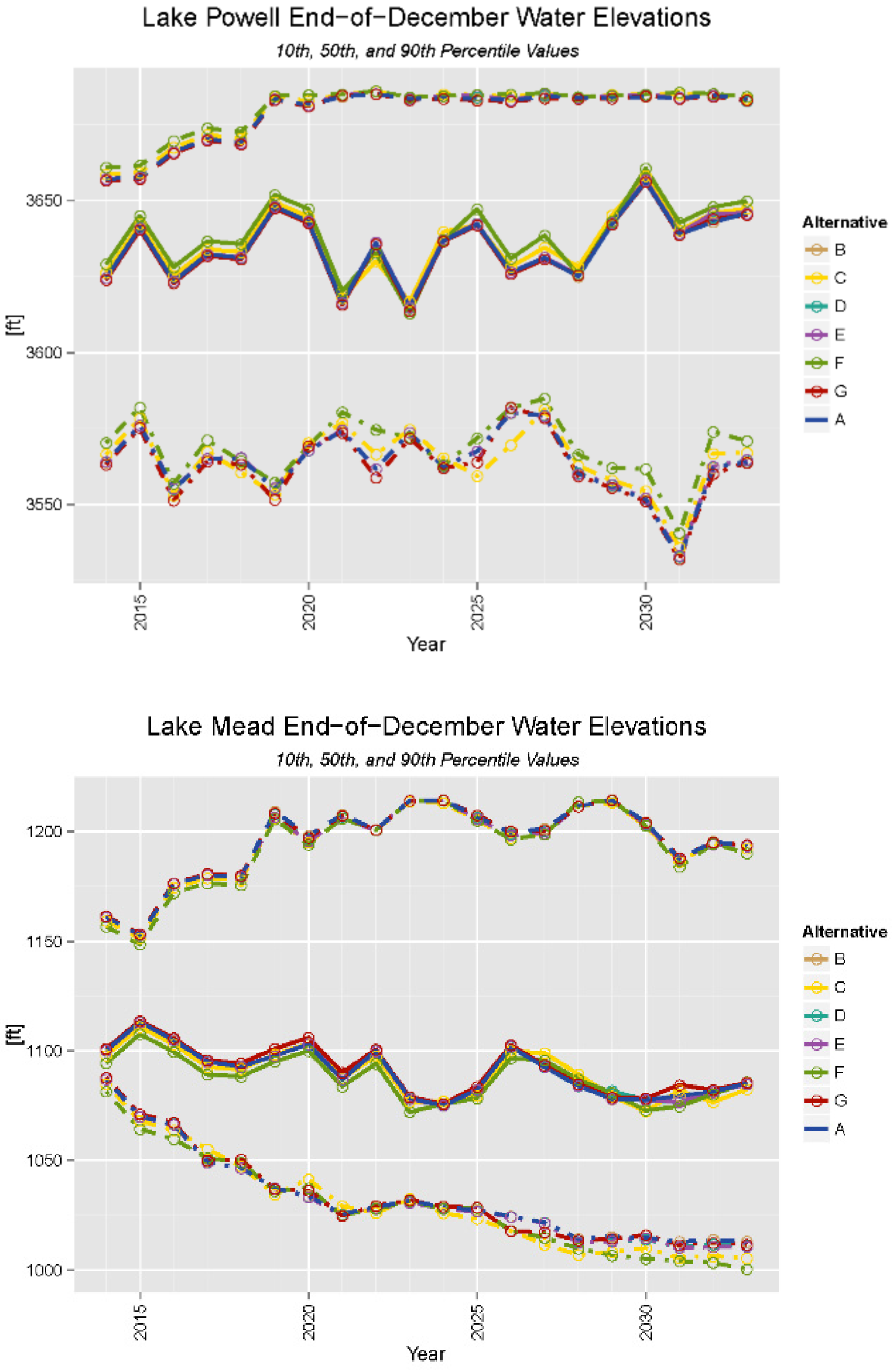

FIGURE 4.2-5 Lake Powell (left) and Lake Mead (right) End of Calendar Year Pool Elevation for 21 Hydrology Traces and Seven Alternatives

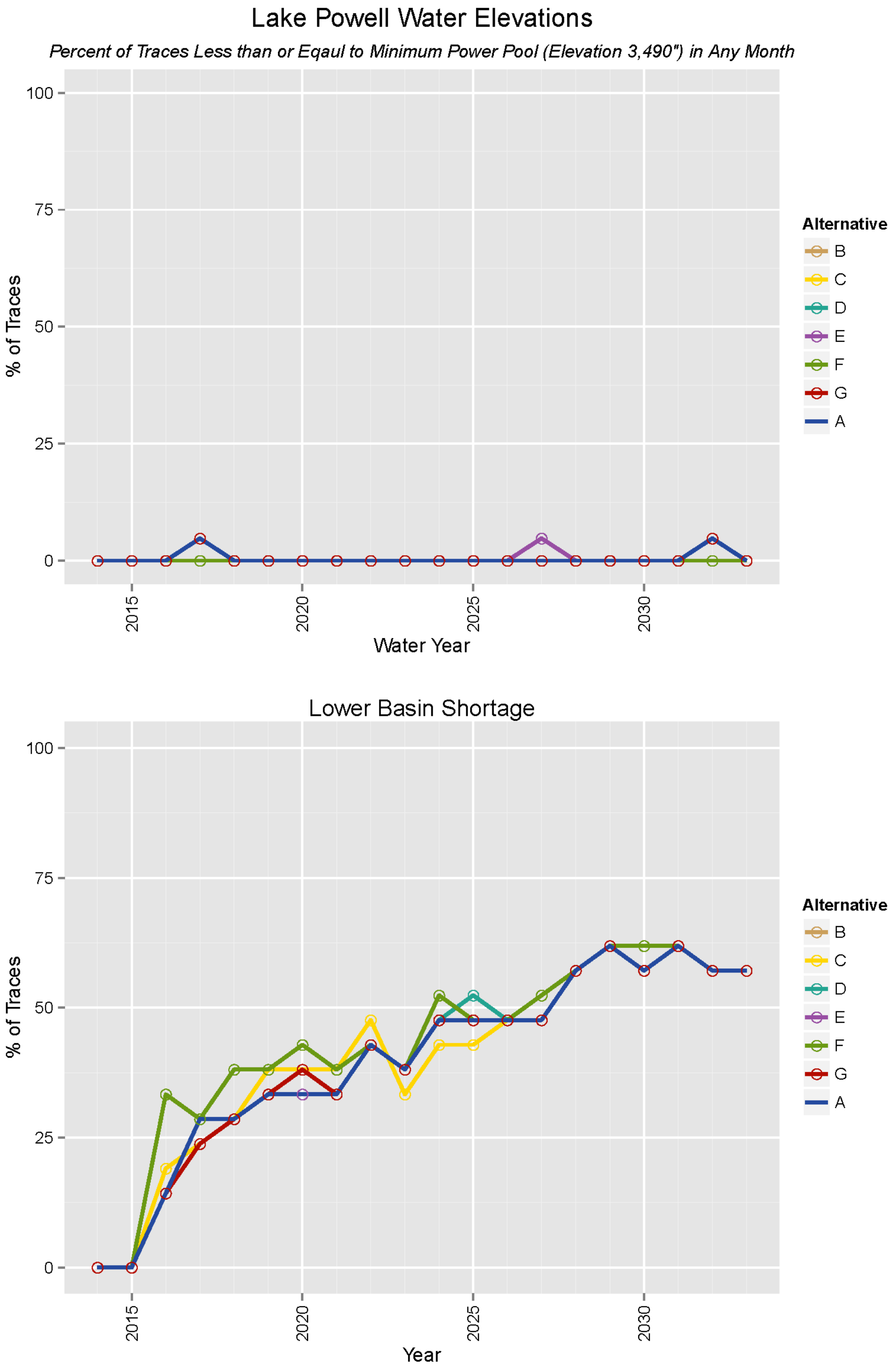

FIGURE 4.2-6 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces and Seven Alternatives

Frequency of Deviation from Alternative A with Regard to Lake Powell Annual Operating Tier as Specified by the 2007 Interim Guidelines. Figure 4.2-7 shows the frequency of deviation from Alternative A with regard to Lake Powell annual operating tier pursuant to the 2007 Interim Guidelines. This frequency was calculated as the number of years in which an alternative was modeled to be in an operating tier that is different from the modeled operating tier of Alternative A for the same year and trace combination divided by the total number of years (420 years for the 20-year period). For 2014–2026, the operating tiers pursuant to the 2007 Interim Guidelines were used; for 2027–2033, the operating tiers were defined as either an 8.23-maf release or a release greater than 8.23 maf.[4] Operations under most of the alternatives do not result in a different operating tier from that under Alternative A. Of those alternatives that do show differences, the percentage of time in a different tier ranged from 0 to 15.4%. Alternatives with an October through December release volume other than 2,000 kaf occasionally result in a different operating tier from Alternative A. Of the alternatives,

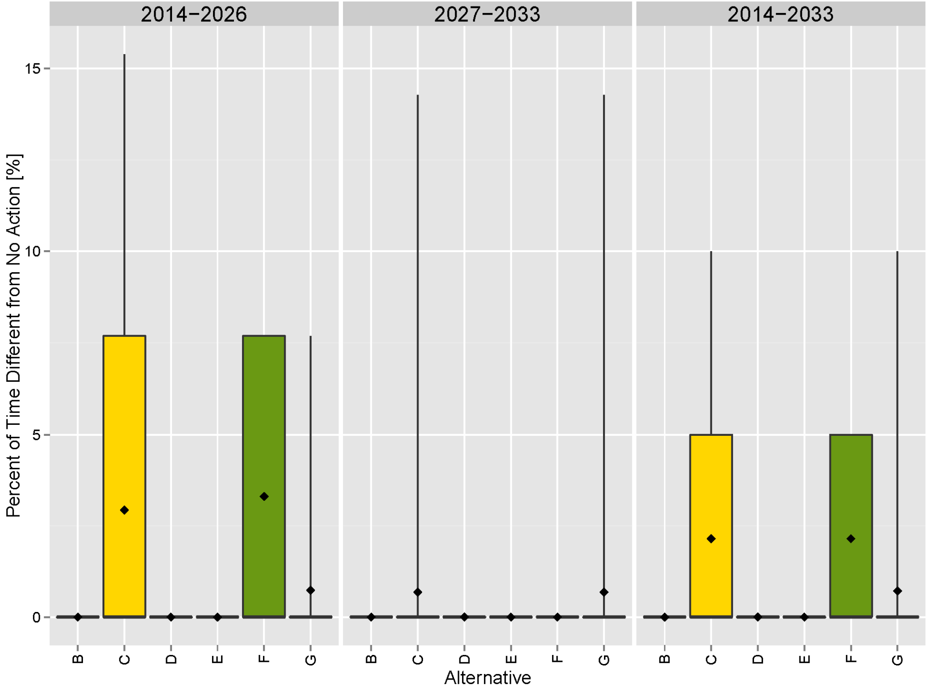

FIGURE 4.2-7 Percentage of Time in Different Operating Tier than Alternative A (The percentage of time in a different operating tier than the No Action Alternative is calculated for each trace and time period. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

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[4] Under the 2007 Interim Guidelines, Lake Powell operates in four possible operating tiers through a full range of reservoir elevations and releases. The Interim Guidelines are in place through 2026 and include a provision that, beginning no later than December 31, 2020, the Secretary of Interior shall initiate a formal review for purposes of evaluating these Guidelines. It is unknown what the outcome of the review will be, including whether or how new guidelines will be implemented. Unless new guidelines are implemented, after 2026, Lake Powell will revert back to the Interim Guidelines' No Action Alternative with tiers defined as either an 8.23-maf release or a release greater than 8.23 maf.

Alternative C is in a different operating tier most frequently, an average of 2.1% of the time during the 20-year LTEMP period. If an alternative is in a different operating tier one year, it is more likely to be in a different operating tier than Alternative A in a following year, and the difference in a year-by-year comparison can cascade through the end of the period.

Probability over Time of Lake Powell Being in Each Operating Tier as Specified in the 2007 Interim Guidelines. Figures 4.2-8 and 4.2-9 show the frequency of occurrence for Lake Powell operating tiers for each alternative during (Figure 4.2-8) and after (Figure 4.2-9) the interim period. The plots indicate that the frequency of each of the tiers is very similar across all alternatives, evidenced by the interquartile, minimum, and maximum values as well as the median and mean values. For all alternatives, the Upper Elevation Balancing Tier is the most common, followed by the Equalization Tier, then the Mid-Elevation Release Tier, and, lastly, the Lower Elevation Balancing Tier. Similar consistency across alternatives is evident in the period 2027–2033.

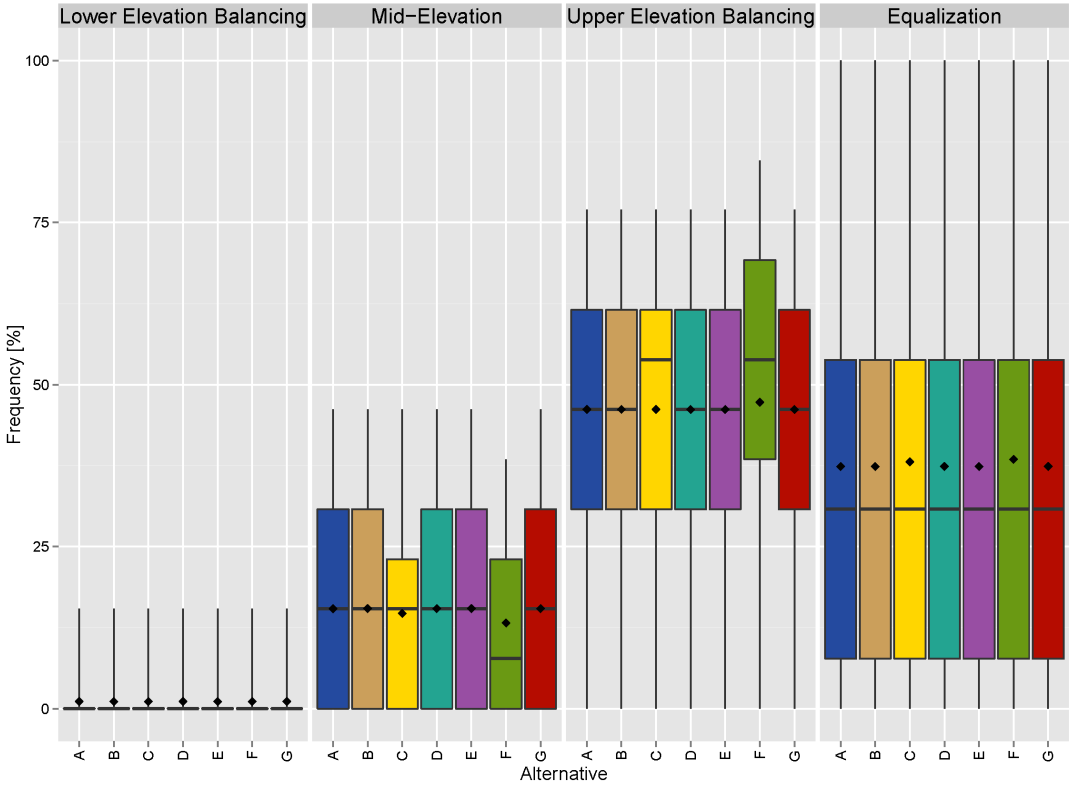

FIGURE 4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

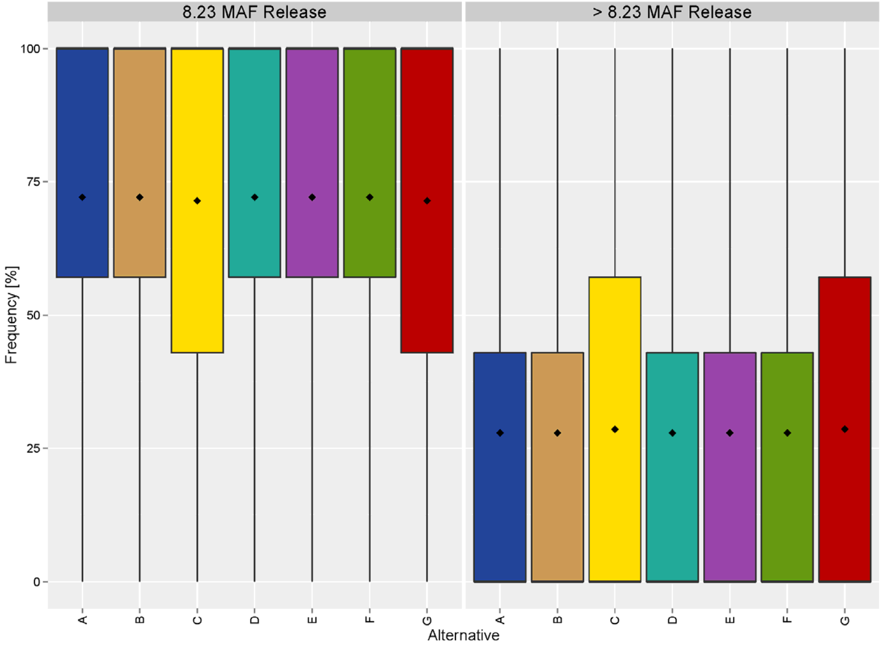

FIGURE 4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Frequency and Volume of Modeled Annual Release Extending Beyond the Water Year. The frequency of modeled annual release extending beyond the water year is shown in Figure 4.2-10. The average number of years with annual releases extending beyond the water year in any 20-year trace is less than 1 for all alternatives, but ranges from 0 to 2. For most action alternatives (except for Alternative B),
the average number of years when annual release extends beyond the water year is less than under Alternative A. In addition, Alternatives C, E, and F reduce the maximum number of annual releases that extend beyond the water year from 2 to 1 per trace. See Section 4.2.2.1 for more details related to the effects due to differences in equalization releases.

The volume of annual releases extending beyond the water year is also similar across alternatives. Across all alternatives, most of the volumes are 0 kaf, with the majority of the remaining volumes less than 500 kaf, and a handful of occurrences ranging up to 2,000 kaf in 1 year. For the action alternatives, the volumes of annual releases extending beyond the water year are generally less than, though sometimes equal to, those under Alternative A. (See Appendix D for detail.)

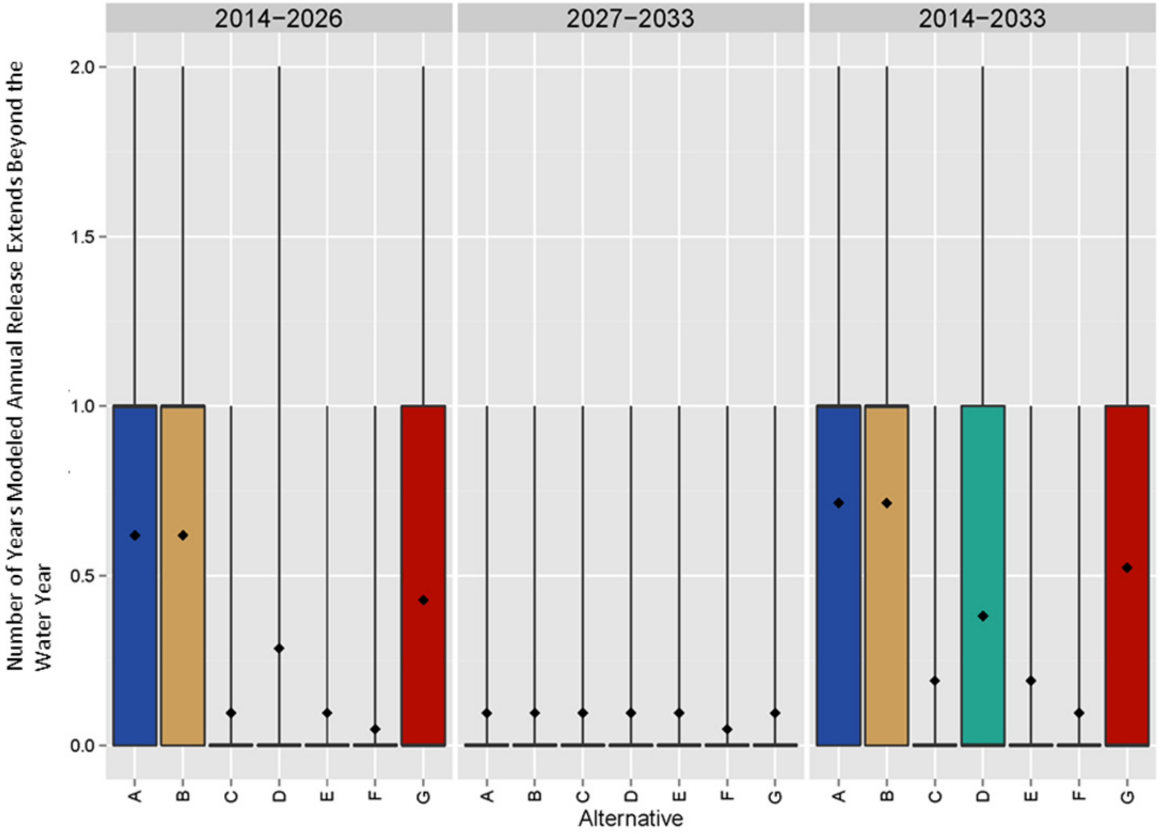

FIGURE 4.2-10 Frequency of Occurrence of Modeled Annual Releases Extending Beyond the Water Year per 20-Year Trace for Each of the Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.2.2.2 Water Quality

This section discusses the general results of the water quality analyses and focuses on impacts on water temperature and salinity. Overall, there is little difference expected in water quality among the different alternatives. The monthly and daily flow characteristics of alternatives do not vary drastically; any small changes are expected to be comparable across all alternatives.

Water Temperature

This section presents a quantitative description of the modeled temperatures and overall trends (e.g., seasonal changes) within and among the alternatives. More detailed analysis, as it relates to specific resources, is provided within the applicable resource sections.

In general, Glen Canyon Dam operations under the various alternatives are not expected to significantly affect Lake Powell reservoir water quality parameters; however, the dam outlet temperature and thermocline location may be a factor in determining effects on water quality downstream.

Lake Powell

As described in Section 3.3.3.2, Glen Canyon Dam release temperatures are highly dependent on the position of the penstocks (i.e., elevation 3,470 ft) relative to the surface of Lake Powell. In general, when reservoir surface elevations are high, releases tend to be cooler because they originate deeper in the reservoir relative to its surface (e.g., from within the hypolimnion). On the other hand, when reservoir surface elevations are low, withdrawals tend to be warmer because they originate closer to the surface (i.e., from the metalimnion or upper hypolimnion). Regardless of the alternative analyzed, temperature and elevation are highly correlated.

The impact of HFEs on the water quality of Lake Powell will depend on reservoir elevation (Reclamation 2011b). At moderate to high reservoir levels, withdrawal of water for HFEs is not expected to negatively affect water quality in the reservoir. Releases in March–April would occur during the spring recirculation period of the reservoir, and releases in October–November would occur at the end of the thermal stratification period, when surface temperatures are the warmest (Vernieu 2010). At low reservoir levels, such as during 2005, water released for an HFE could draw from the warm top layer of the reservoir, especially in October–November, and result in warm dam releases, but it would not likely affect the overall reservoir temperature or water quality (Reclamation 2011b).

Examination of the modeling results for effects of alternative operations on release temperatures indicated that annual inflow volume to Lake Powell had a greater influence on the release temperature than the operational differences in monthly and daily flows. Under drought conditions, such as those seen recently (e.g., 2005–2010), release temperatures tend to be consistently higher because reservoir elevations are generally low and releases originate closer to the reservoir surface. However, during extreme drought, the elevation of Lake Powell may drop below the minimum power pool elevation of 3,490 ft AMSL. If this occurs, releases cannot be made from the powerplant penstocks and are instead routed through the river outlet tubes located 3,374 ft AMSL. Because water at the level of the river outlet tubes is generally colder due to its depth, release temperatures could drop to less than 10°C. If the reservoir elevations were to drop further, closer to the elevation of the river outlet tubes, the releases would again gradually warm (Reclamation 2007a).

Figure 4.2-11 compares the mean temperatures of water released from Glen Canyon Dam for wet, medium, and dry hydrology traces. These figures illustrate how little temperature variation there is among the seven LTEMP alternatives (within any given trace) compared to the much larger variation across the traces. For example, the minimum, maximum, and mean values for modeled temperature at Glen Canyon Dam vary less than 0.3°C, 0.7°C, and 0.2°C,

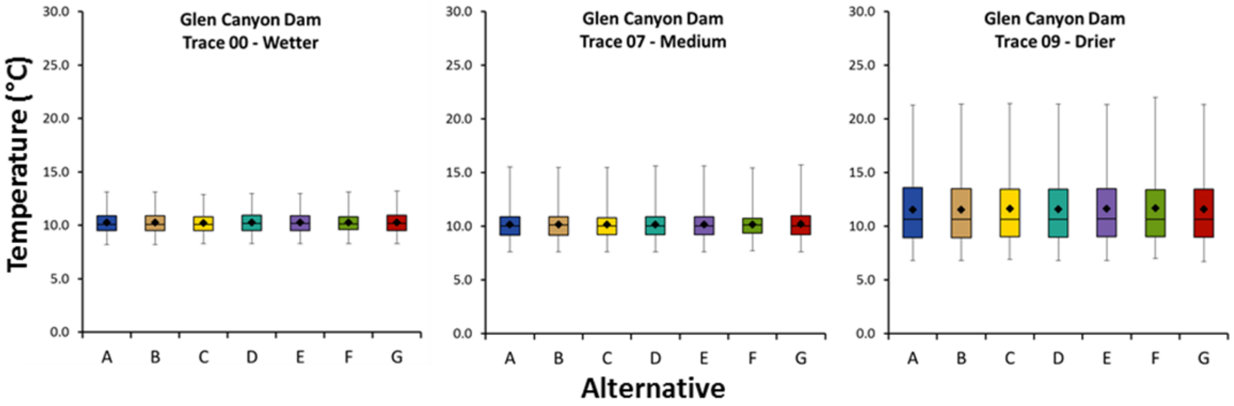

FIGURE 4.2-11 Comparison of Mean Water Temperatures for Representative Wetter, Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

respectively, among the alternatives for any given trace. However, across hydrology traces the minimum, maximum, and mean values vary over a range of approximately 1.5°C, 8.8°C, and 1.5°C, respectively.

Drier hydrology traces exhibit greater variation in temperature values and more pronounced differences among alternatives, although the actual differences in means are still quite small (i.e., less than 0.2°C). This is because drier traces have lower overall inflow volumes and consequently lower reservoir levels in most years. The released water associated with lower reservoir elevations is drawn from closer to the surface, where it is more sensitive to atmospheric conditions (e.g., air temperature and solar radiation). However, the release water associated with higher reservoir elevations (resulting from higher cumulative inflow volumes) tends to be drawn from deeper in the hypolimnion, which exhibits a more stable temperature profile. Therefore, operational differences that have negligible perceived impacts on temperature at larger water volumes (i.e., wetter traces) can become more pronounced during drier traces.

Figure 4.2-12 illustrates mean seasonal[5] release temperatures at Glen Canyon Dam, aggregated across the 21 hydrology traces for the modeled 20-year time period. Overall, the seasonal temperature ranges are similar across alternatives.

The minimum mean release temperatures occur in the spring, with aggregated mean values ranging from 9.0 to 9.3°C, depending on alternative. The lower end of this range is characteristic of Alternatives A and B. The top end of this range is associated with Alternative F, possibly because the reservoir elevation is lower by May after sustained higher releases in March and April. Considering all traces across the entire modeled time period, the full range of mean

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[5] For the purposes of this discussion, seasonal temperatures are represented by 3-month periods representing the standard meteorological seasons: December–February for winter; March–May for spring; June–August for summer; and September–November for fall.

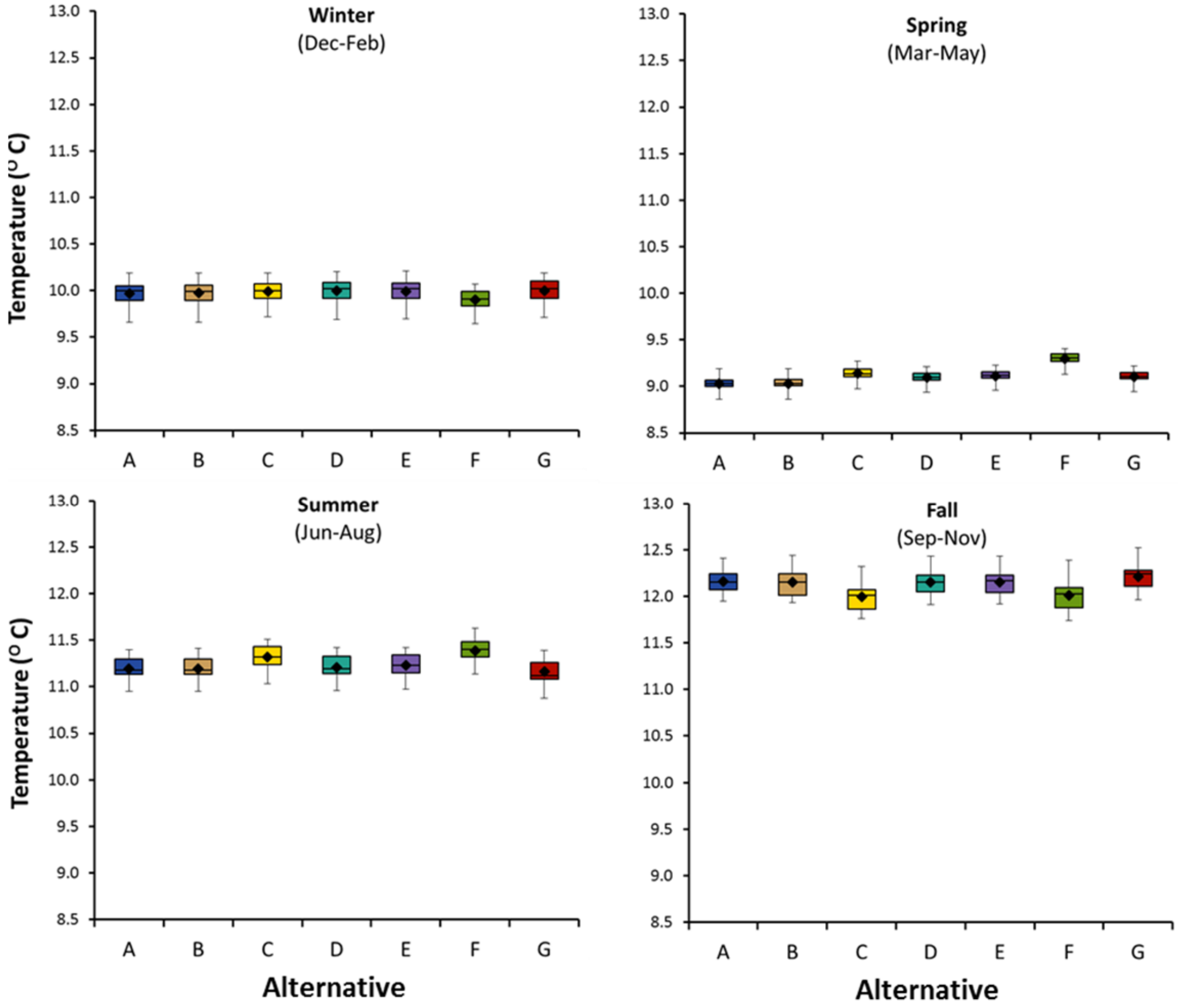

FIGURE 4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

spring release temperatures varied from around 8.8 to 9.5°C, depending on alternative. The bottom of this range is generally representative of wetter traces (i.e., higher reservoir elevations), and the top of this range is generally represented by drier traces (i.e., lower reservoir elevations).

The peak mean release temperature occurs during the fall, with aggregated means ranging from 12.0 to 12.2°C, depending on alternative; however, there are no significant differences among alternatives in mean release temperature, even in the fall. Considering all traces, the full range of mean fall release temperatures varied from around 10.7 to 14.3°C, depending on the alternative. As with spring temperatures, the bottom of the fall range is generally representative of wetter traces (i.e., higher reservoir elevations), and the top of this range is generally represented by drier traces (i.e., lower reservoir elevations).

Glen Canyon Dam release temperatures (for all alternatives) are lower in spring than in winter, and lower in summer than in fall. This difference is a result of the lag time associated with warming and cooling of Lake Powell (refer to Section 3.3.3.1 for further information on Lake Powell hydrology).

Colorado River between Glen Canyon Dam and Lake Mead

Once released from the dam, typically warmer air temperatures regulate river temperature. Consequently, the warmer spring and summer months see significant downstream warming while colder winter and fall months have much less downstream warming, and perhaps even downstream cooling (Voichick and Wright 2007). Tributaries, such as the Little Colorado River (river mile [RM] 61), provide warmer inflows in the summer and cooler inflows in the winter (refer to Section 3.3.4.2 for additional details related to Colorado River water temperatures between Glen Canyon Dam and Lake Mead.)

Comparisons of the seasonal trends in river temperatures among the seven LTEMP alternatives are illustrated in Figure 4.2-13 at locations between Glen Canyon Dam (RM 0) and Diamond Creek (RM 225). Temperatures presented in these figures represent modeled values aggregated across the 21 hydrology traces. In general, projected temperatures vary due to three factors: release volume, release temperature, and downstream meteorology and hydrology. The rate at which the water released from a reservoir approaches ambient air temperature as it travels downstream depends on these factors as well (Reclamation 2007a).

Overall, mean seasonal temperatures increase as water moves downstream. Winter river temperatures are the coldest of any season. Mean winter temperatures ranged from 9.7 to 10.2°C at RM 0 (Lees Ferry), 9.9 to 10.4°C at RM 61 (Little Colorado River), 10.2 to 10.6°C at RM 157 (Havasu Creek), and 10.4 to 10.8°C at RM 225 (Diamond Creek). These data also indicate that within any given alternative, there is a very small longitudinal gradient (i.e., at most a 0.5–0.7°C difference for mean; 1.0–1.1°C difference across the full range of values) between the mean temperatures at the Glen Canyon Dam outlet and Diamond Creek during the winter.

For all alternatives, significant downstream warming (i.e., between 6.0 and 7.2°C difference for mean; 6.8–8.1°C difference across full range of values) is expected in the summer. Average summer temperatures are the warmest of any season, ranging from 11.3 to 12.1°C at RM 0, 12.9 to 14.0°C at RM 61, 15.3 to 17.0°C at RM 157, and 16.9 to 19.2°C at RM 225. More details related to temperature values and ranges for each of the seven LTEMP alternatives are presented in Section 4.2.3.

A number of experimental actions (described in detail in Section 2.3) would be incorporated into many of the LTEMP alternatives. Operational actions such as HFEs, TMFs, low summer flows, and sustained low flows for benthic invertebrate production may have noticeable impacts on water temperature at the Glen Canyon Dam outlet and downstream. Past experimental events and water temperature models have provided the following insights into water temperature response to these experimental actions.

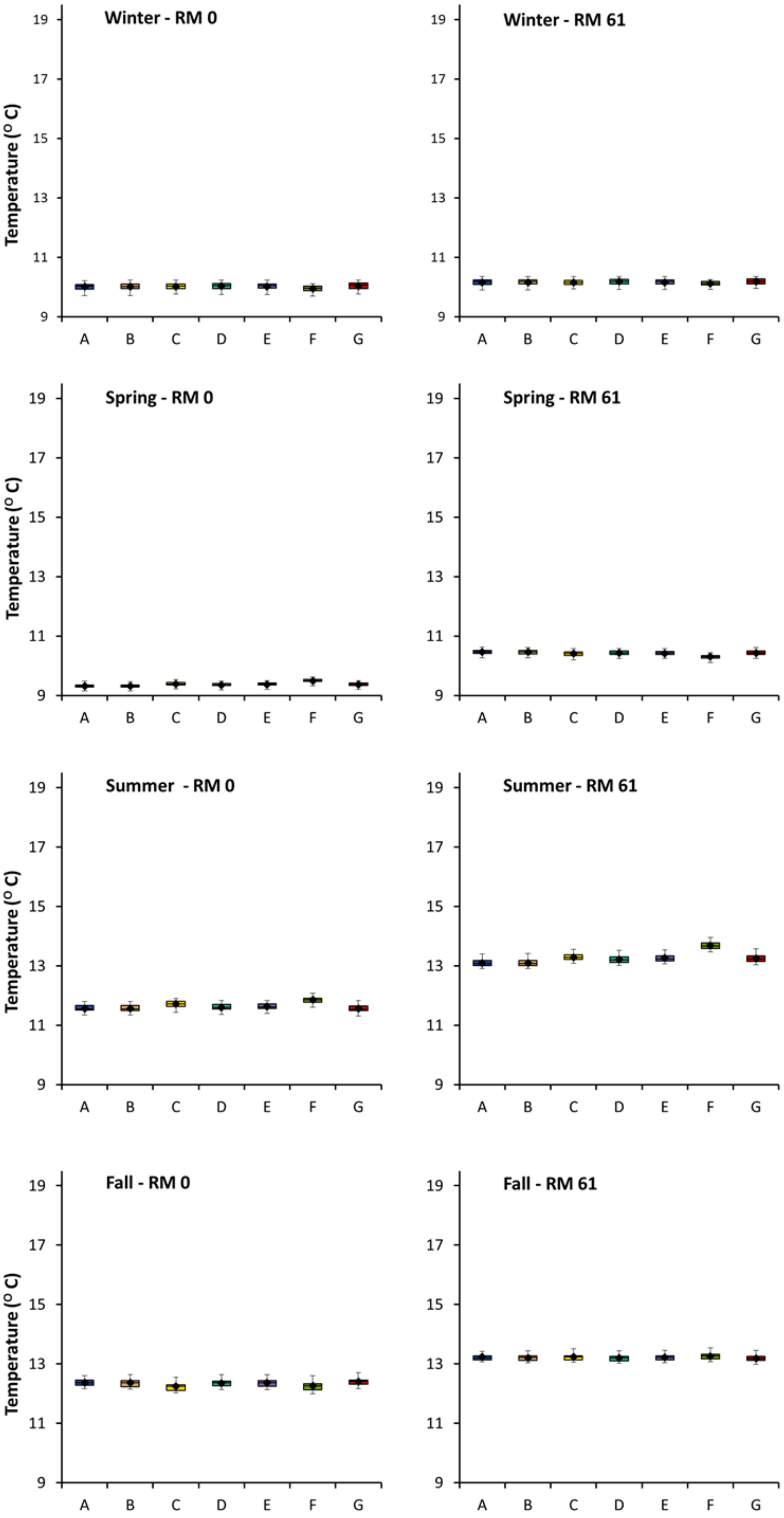

FIGURE 4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

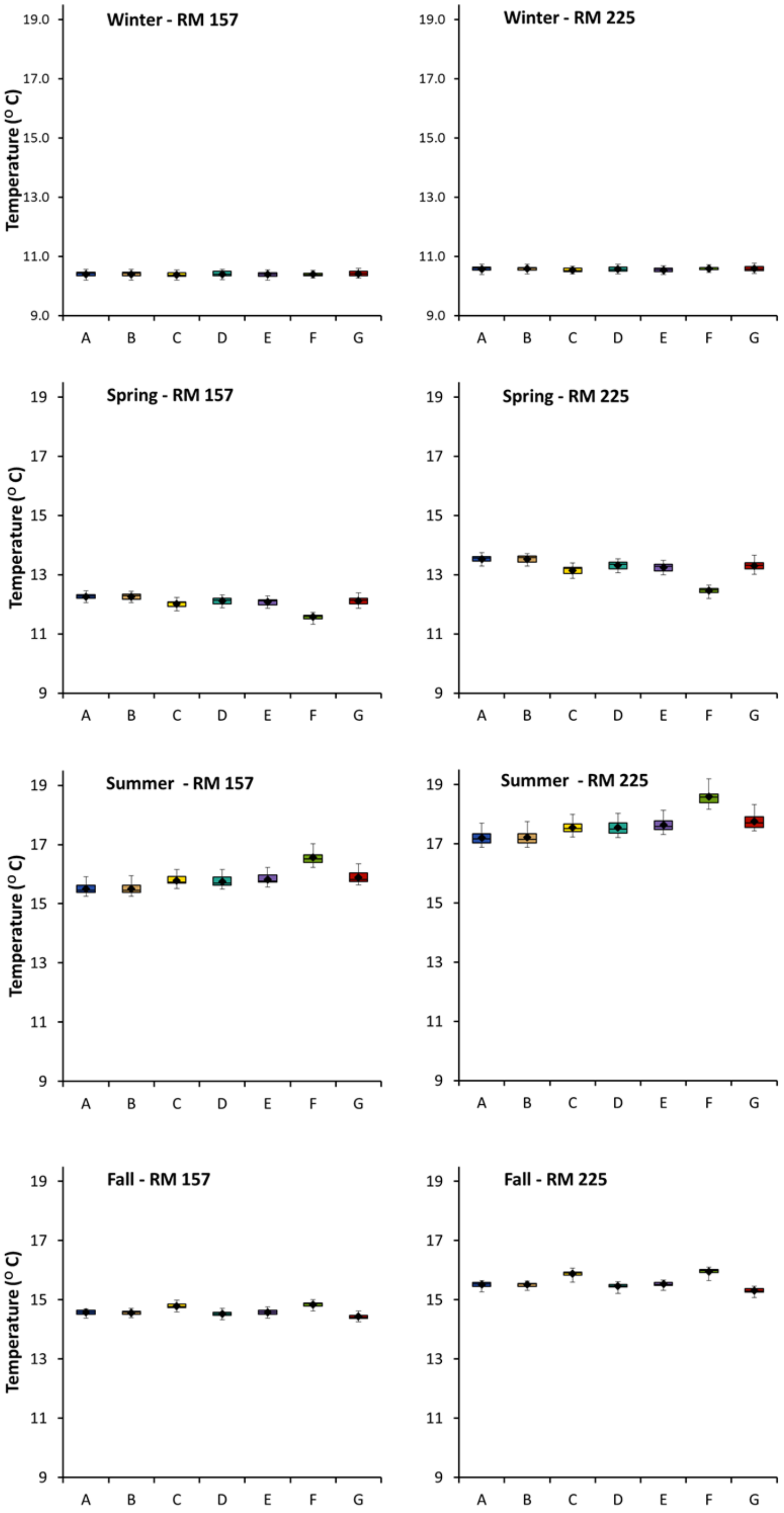

FIGURE 4.2-13 (Cont.)

The magnitude, duration, and seasonal timing of an HFE vary according to sediment input from the Paria River and other resource conditions. In the limited number of HFEs run and analyzed from 1996 to 2011 (i.e., fall of 1996, 2004, and 2008; spring of 2008), effects on water temperature have been observed to be minor and short term, and to result in slight reductions in downstream water temperature (Vernieu et al. 2005; Reclamation 2011b). Modeling conducted for this EIS reflects these observations. In general, fall end-of-month temperatures are approximately 1°C higher at Diamond Creek (RM 225) in years without an HFE event than in comparable fall seasons with HFEs. Downstream temperature cooling is similarly expected for spring HFEs, although temperature decreases are expected to be smaller (end-of-month temperatures 0.1–0.5°C cooler). Considering that the November 2012 HFE (releasing approximately 42,000 cfs for 24 hr) and the November 2013 HFE (releasing nearly 35,000 cfs for 96 hr) took only 55 and 54 hr, respectively, to reach Pearce Ferry (i.e., RM 279) (NPS 2012e, 2013j), any warming would be expected to be small and of short duration.

If very large amounts of sediment are input by the Paria River, HFEs may have durations of up to 336 hr under Alternative G and 250 hr under Alternative D. Modeling indicates that, when considering HFEs of similar magnitude (occurring in the fall), downstream warming increases slightly and gradually as the duration of the HFE increases. For example, the difference between the downstream warming of a 48-hr and 336-hr HFE (both at 45,000 cfs) was less than 1°C.

TMFs have not been tested in the Colorado River; therefore, water temperature effects of these flows are uncertain. Overall, the magnitude of flow changes for TMFs are smaller compared to HFEs. As a result, perceptible temperature changes at the dam or downstream are not expected. For example, a TMF modeled to run for 72 hours at a steady flow of 20,000 cfs does not exhibit noticeable effects on modeled water temperatures.

Experimental low summer flows could occur under Alternatives C, D, and E. Low summer flows are run at approximately 8,000 cfs for the months of July, August, and September. Modeled low summer flows show similar water temperatures just downstream of the dam, with slightly higher downstream warming, when compared to similar conditions without low summer flows. This is because lower velocity flows have a higher surface-area-to-volume ratio (compared to high flows) and greater exposure time with the ambient air, which facilitates water warming through solar radiation and atmospheric heat exchange (Vernieu et al. 2005). When considering individual model traces, variations in downstream temperatures were generally greatest in July (nearly 3°C warmer for low summer flows) and least in September (about 1°C warmer for low summer flows), with August falling in the middle (approximately 2°C warmer for low summer flows).

Macroinvertebrate[6] production flows are one of the experimental modifications to base operations for Alternative D that could be tested during the LTEMP period. For this experiment, flow on Saturdays and Sundays of May through August would be held steady at the minimum monthly flow. These stable weekend flows would be tested to determine whether they improved

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[6] Animal without a backbone or spinal column, usually replaced by a hard exoskeleton or shell. Examples include insects, worms, crustaceans, snails, or clams.

invertebrate production. This operational action increases the mean daily flows during the weekdays. Water temperature modeling indicates that release temperature would change little (e.g., ±0.01°C), and warming at downstream locations during the summer, as indicated by maximum temperature, would be less than 1°C (0.03°C at the confluence with the Little Colorado River [RM 61] and 0.12°C at Diamond Creek [RM 225]).

Lake Mead

Potential water quality issues in Lake Mead were evaluated based on a concern expressed by Southern Nevada Water Authority that water quality could be affected by significant shifts in the temperature of Colorado River water reaching Lake Mead. The temperature of the water determines its density and its position within the water column of Lake Mead. Warmer Colorado River inflows would enter and flow through Lake Mead in the middle of the water column (Tietjen 2014), and this could then have adverse impacts on bottom water oxygen concentrations, effectively trapping below the inflow area low-DO water that does not mix completely and that could slowly expand down the reservoir.

Modeling was conducted by the Southern Nevada Water Authority on a selected set of LTEMP alternatives (Alternatives A, E, and F) and years (2-year runs) that were considered to represent a reasonable range of potential outcomes at a much finer resolution of temporal and spatial scales compared to other modeling efforts. Because Alternative F was expected to produce the warmest water temperatures of all alternatives in the summer, it was chosen as the potential highest risk case. Modeling indicated there would be negligible differences in the distribution of low-DO areas among modeled alternatives (Tietjen 2015). The input parameters for modeling were limited by the quality of the boundary conditions at the Colorado River inflow. Prediction errors in the models producing this data will propagate through the Lake Mead model.

HFEs were not shown to have measurable impacts on Lake Mead water quality. They are expected to mix a portion of the low-DO water near the sediment-water interface up into the water column near the inflow area to Lake Mead. This should act to reduce (or possibly eliminate) any observed low-oxygen problems (Tietjen 2014).

Salinity

The projected salinity concentrations presented in Figure 4.2-14 are the flow-weighted annual means over the 20-year LTEMP period at Lees Ferry (no criteria established for this location). The results assume continuation of existing and implementation of planned salinity control programs and projects.[7]

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[7] Salinity in the river may vary depending on the annual hydrology, but that variability is unrelated to the implementation of any of the LTEMP alternatives.

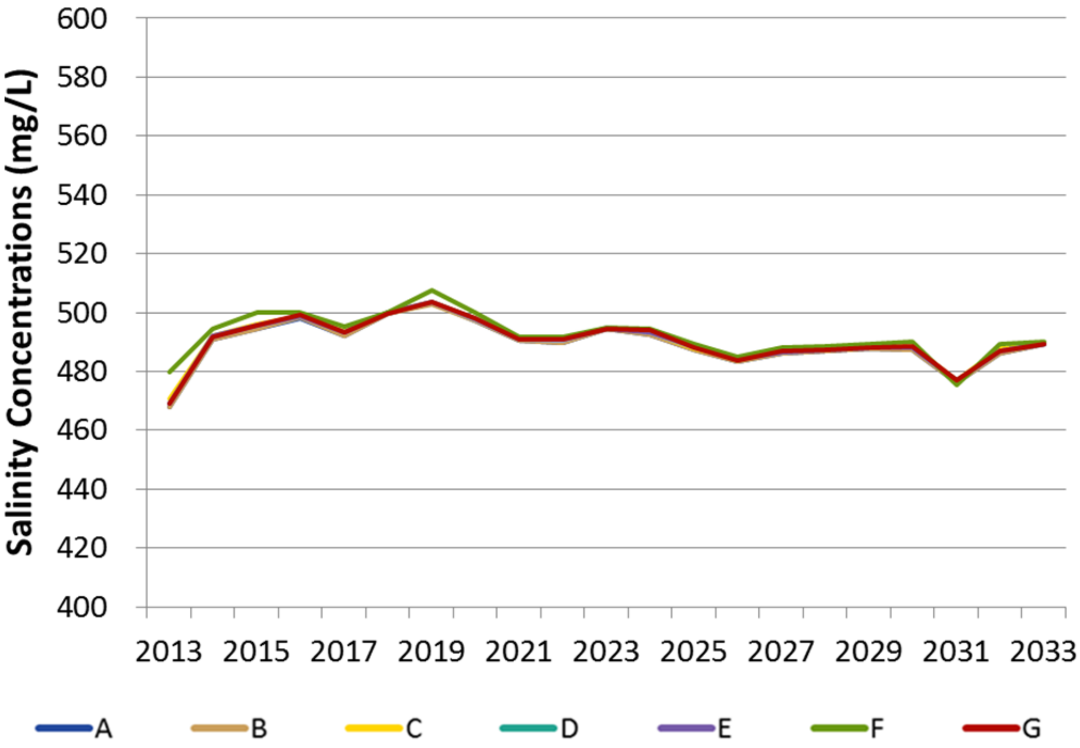

FIGURE 4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at Lees Ferry

Under all alternatives, salinity would increase as water moves downstream. Mean concentrations at Lees Ferry are 490 mg/L, with a full range from 468 to 508 mg/L considering the entire modeled period across all seven LTEMP alternatives (Figure 4.2-14). Considering all years individually, the differences in salinity concentrations among the different alternatives is less than 2.5%.

Other Water Quality Parameters

No significant impacts on other water quality parameters (e.g., DO, nutrients, metals, and organics) are expected under any LTEMP alternative. In addition, research (Reclamation 2011b) has indicated that the potential effects of HFEs on other water quality parameters (e.g., turbidity and DO) below the dam would only be temporary, and any observed effects would recover quickly when lower flows returned (refer to Section 3.3.4.2 for more details on the effects of HFEs on water quality of the Colorado River below the Glen Canyon Dam).

With respect to turbidity, a positive correlation with tributary sediment input is also expected (refer to Section 3.3.4.2 for more information on the relationship between turbidity and suspended sediment). However, no impacts are expected because operations will not affect tributary sediment input and, therefore, will not result in differences among the alternatives.

Although an increase in visitor use could result in an increase in the occurrence of pathogens, current National Park Service (NPS) regulations limit the number of river boating trips and passengers. The capacity set by the Colorado River Management Plan of 2006 is reached every year. As a consequence, the numbers of angling and boating trips are not expected to change as a result of any of the alternatives, and no difference in pathogenic or disease-causing organisms is expected because there will be no variation in the number of visitors. However, certain types of flow have been associated with local occurrences of high pathogenic bacterial counts. For example, low steady flows, particularly during periods of high recreational use, can result in local areas of exceedances due to the buildup of bacteria along the shoreline. Higher-volume flows, including HFEs, could mobilize these bacteria harbored in streamside sediments from past recreational use, in effect flushing out areas of concern, but also temporarily increasing downstream bacteria counts. However, any increase would be short lived (i.e., hours or days depending on the duration of the high-flow event) and would be followed by a decrease in the areas flushed by the high flows. As a result, high flows are not likely to result in measurable increases in bacteria or pathogens, given the short time period and the dilution by a large volume of water. However, alternatives with long-duration lower and steadier flows may lead to a higher potential for contamination from bacteria and other pathogens and, thus, could increase the possibility of health hazards associated with contaminated water. Years with low release volumes (<8.23 maf) would have a higher probability of occurrence. The probability of this contamination occurring is expected to be very low, and the effects would be localized for all alternatives. However, there are potential differences among alternatives related to the occurrence of low flows and HFEs. Alternatives C, D, and E include low summer flow experiments during which there could be a slight increase in the potential for bacteria and pathogen contamination compared to Alternatives A and B. Alternatives F and G have the highest (though still low) potential, given the annual occurrence of steady flows.

4.2.3 Alternative-Specific Impacts

The following sections describe the range of alternative-specific impacts on hydrology, (i.e., reservoir releases and elevations, river flows) and water quality. Both water delivery metrics and other system relevant conditions (e.g., reservoir elevations) are discussed for each alternative. Each alternative was modeled using 21 different potential scenarios that accounted for uncertainty in future hydrologic conditions. Figures 4.2-1 through 4.2-14 show the results for all alternatives; plots comparing each action alternative to Alternative A can be found in Appendix D.

The modeling predicted that inflow hydrology has the most effect on operating tier, release volume, and resulting reservoir elevations, whereas the alternatives show smaller effects. Differences among the LTEMP alternatives are expected to be negligible with regard to salinity, turbidity, nutrients, DO, metals/radionuclides, or organic/other contaminants. As a result, temperature, bacteria, and pathogens are the only water quality parameters discussed in this section. When analyzing the temperature differences between the LTEMP alternatives, differences of less than 0.5°C are not regarded as significant because of the inherent temperature variability observed in the natural environment, combined with the reported standard error (i.e., less than 0.5°C) for the temperature model applied (Wright, Anderson et al. 2008). Thus, only temperature differences greater than 0.5°C are explained in further detail.

4.2.3.1 Alternative A (No Action Alternative)

During the interim period (through 2026), Alternative A would operate at times within each of the four operating tiers, at the following mean annual frequencies: Upper Elevation Balancing Tier—46.2%; Equalization Tier—37.4%; Mid-Elevation Release Tier—15.4%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative A has annual releases of 8.23 maf in an average of 72.1% of years and annual releases greater than 8.23 maf in an average of 27.9% of years.

During wet years, the modeling showed that Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. For Alterative A, the mean number of occurrences of annual release extending beyond the water year per 20-year trace is 0.7, with a range of 0 to 2 occurrences per 20-year period. The mean volume of annual release extending beyond the water year is 248 kaf, with a range from 0 to 2,021 kaf.

Under Alternative A, monthly reservoir releases are generally higher in December, January, July, and August and lower in the other months. In the years 2014–2020, when HFEs would be implemented under Alternative A, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell elevations would vary significantly with hydrology but would vary little by alternative. Depending on hydrology, Lake Powell elevations can be anywhere in the full range of operating elevations. Under Alternative A, the median elevation for Lake Powell at the end of December was about 3,630 ft throughout the 20-year LTEMP period. End-of-December elevations ranged from about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles, respectively. Under Alternative A, this modeling showed two instances out of 420 (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490-ft minimum power pool.

Lake Mead elevations would also vary significantly with basin hydrology and the resulting Lake Powell release, but would vary little by alternative. Depending on hydrology, Lake Mead elevations can be anywhere in the full range of operating elevations. Under Alternative A, the median elevation for Lake Mead at the end of December ranged from about 1,100 ft near the beginning of the period to about 1,080 ft near the end of the 20-year LTEMP period. End-of-December elevations at the beginning of the period ranged from about 1,080 ft to about 1,160 ft at the 10th and 90th percentiles, respectively, and from about 1,020 ft to about 1,210 ft near the end of 20-year LTEMP period. Under Alternative A, the percentage of traces with Lower Basin Shortages is 0 for the first 2 years of the period, and then increases to 62% of traces near the end of the 20-year period.

Mean monthly volume under Alternative A would be similar to current conditions and would be highest during months with relatively high hydropower demand (December, January, June, July, and August), when volume would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would be approximately 570,000 to 1,200,000 ac-ft in other months.

Mean daily flows under Alternative A also would represent no change from current conditions, and would be highest in the higher volume months of December, January, June, July, August, as well as September, when flows would range from approximately 11,200 to 24,600 cfs under the scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to 14,400 cfs in other months.

Under Alternative A, the allowable daily range is dependent on monthly volume and ranges from 5,000 to 8,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily change would occur in December, January, July, and August, when mean daily change would vary from about 2,000 to 7,800 cfs (Figure 4.2-4). In other months, mean daily change would range from 2,600 to 6,400 cfs.

Seasonal temperature data and trends are provided in Table 4.2-2 for the seven LTEMP alternatives as a function of distance downstream from RM 0 (i.e., Lees Ferry) through RM 225 (i.e., Diamond Creek). The minimum, maximum, and mean temperature data presented in these figures represent values aggregated across the 21 hydrology traces over the 20-year LTEMP period.

For Alternative A, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.6°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 5.6°C (11.6–17.2°F) difference. Spring temperatures warm around 4.2°C (9.3–13.5°C); fall temperatures warm about 3.1°C (12.4–15.5°C).

Under Alternative A, there would be no change from current conditions in the occurrence of bacteria or pathogen contamination along shorelines. The expected probability of this contamination occurring is very low, and would be localized and temporary.

In summary, Alternative A would result in no changes in current conditions related to hydrology or water quality.

4.2.3.2 Alternative B

Alternative B would show little or no difference from Alternative A with regard to operating tier, in almost every one of the 21 hydrology traces modeled. This is the smallest difference among all of the action alternatives. Compared to Alternative A, Alternative B would result in the same frequency of operating tiers, the same average number of occurrences of modeled annual releases extending beyond the water year, and the same volume of annual

TABLE 4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees Ferry to Diamond Creek

	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
Season	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Winter (December–February)												
Alternative A	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative B	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative C	9.8	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.5	10.4	10.5	10.7
Alternative D	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative E	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.5	10.7
Alternative F	9.7	9.9	10.1	9.9	10.1	10.3	10.3	10.4	10.5	10.5	10.6	10.7
Alternative G	9.8	10.0	10.2	10.0	10.2	10.4	10.3	10.4	10.6	10.4	10.6	10.8
Spring (March–May)												
Alternative A	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.5	13.3	13.5	13.7
Alternative B	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.4	13.3	13.5	13.7
Alternative C	9.2	9.4	9.5	10.2	10.4	10.6	11.8	12.0	12.2	12.9	13.2	13.4
Alternative D	9.2	9.4	9.5	10.3	10.4	10.6	11.9	12.1	12.3	13.1	13.3	13.5
Alternative E	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.3	13.0	13.3	13.5
Alternative F	9.3	9.5	9.6	10.1	10.3	10.4	11.3	11.6	11.7	12.2	12.5	12.6
Alternative G	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.4	13.0	13.3	13.7
Summer (June–August)												
Alternative A	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	15.9	16.9	17.2	17.7
Alternative B	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	16.0	16.9	17.2	17.8
Alternative C	11.4	11.7	11.9	13.1	13.3	13.6	15.5	15.8	16.2	17.2	17.6	18.0
Alternative D	11.4	11.6	11.8	13.0	13.2	13.5	15.5	15.8	16.2	17.2	17.5	18.0
Alternative E	11.4	11.6	11.8	13.1	13.3	13.5	15.6	15.8	16.2	17.3	17.6	18.1

TABLE 4.2-2 (Cont.)

	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
Season	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Summer (June–August) (Cont.)												
Alternative F	11.6	11.9	12.1	13.5	13.7	14.0	16.2	16.6	17.0	18.2	18.6	19.2
Alternative G	11.3	11.6	11.8	13.0	13.3	13.6	15.6	15.9	16.4	17.4	17.8	18.3
Fall (September–November)												
Alternative A	12.2	12.4	12.6	13.1	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative B	12.2	12.4	12.6	13.0	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative C	12.0	12.3	12.6	13.1	13.2	13.5	14.6	14.8	15.0	15.6	15.9	16.1
Alternative D	12.1	12.4	12.6	13.0	13.2	13.4	14.3	14.5	14.7	15.2	15.5	15.6
Alternative E	12.1	12.4	12.6	13.0	13.2	13.5	14.4	14.6	14.8	15.3	15.5	15.7
Alternative F	12.0	12.3	12.6	13.1	13.3	13.5	14.6	14.8	15.0	15.7	16.0	16.1
Alternative G	12.2	12.4	12.7	13.0	13.2	13.5	14.3	14.4	14.6	15.1	15.3	15.5

release extending beyond the water year. In addition, the end-of-December elevations under Alternative B for Lake Powell and Lake Mead would be identical to those under Alternative A.

Under Alternative B, monthly reservoir releases would be nearly identical to those of Alternative A. Releases from Lake Powell can vary from Alternative A by up to 4 kaf in 3% of months due to different ramp-down constraints. In years when HFEs would be implemented under Alternative B, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Mean monthly volumes under Alternative B would be identical to those under Alternative A and similar to current conditions. Volume would be highest during months with relatively high hydropower demand (December, January, June, July, and August) when volume would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would be approximately 570,000 to 1,200,000 ac-ft in other months.

Mean daily flows under Alternative B also would be similar to current conditions. They would be highest in the higher volume months of December, January, June, July, and August, as well as September, when flows would range from approximately 11,200 to 24,600 cfs under the scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to 14,400 cfs in other months.

Under Alternative B, the allowable daily change is higher than under Alternative A and ranges from 6,000 to 12,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily change would occur in December, January, July, and August, when mean daily change would vary from about 2,500 to 12,000 cfs (Figure 4.2-4). In other months, mean daily change would range from 3,000 to 10,000 cfs.

Modeled water temperature ranges and means under Alternative B are nearly identical to those under Alternative A (Table 4.2-2), because the two alternatives have the same monthly release volumes. Daily fluctuation differences, which are greater for Alternative B relative to Alternative A, are thought to have a negligible impact on water temperature (Anderson and Wright 2007). Other operational differences between the two alternatives related to ramp rates and test flows (e.g., HFEs, hydropower improvement flows, and TMFs) would not affect seasonal temperature trends.

Under Alternative B, there is a slightly lower probability of the occurrence of bacteria or pathogen contamination along shorelines. This lower probability would result from the slightly higher daily fluctuations under this alternative relative to Alternative A. Experimental hydropower improvement flows would have the lowest probability of occurrence. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative B would result in no change from current condition related to reservoir elevations, annual operating tiers, monthly release volumes, or mean daily flows, but would produce higher mean daily changes in flow. Hydropower improvement flows would cause even greater mean daily flow changes. Compared to

Alternative A, there would be negligible differences in temperature or other water quality indicators, but Alternative B has a slightly lower probability of the occurrence of bacteria or pathogen contamination along shorelines.

4.2.3.3 Alternative C

Alternative C would show little or no difference from Alternative A with regard to operating tier. The October through December release volume for Alternative C is 210 kaf less than Alternative A in an 8.23-maf release year; this difference could result in a slightly higher end-of-December elevation and sometimes a different operating tier. Alternative C would result in a different operating tier from that under Alternative A in 2.1% of years.

The frequency of operating tiers under Alternative C would be very similar to that under Alternative A. During the interim period (through 2026), Alternative C would operate at times within each of the four operating tiers at the following mean annual frequencies: Upper Elevation Balancing Tier—46.2%; Equalization Tier—38.1%; Mid-Elevation Release Tier—14.7%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative C has 1 year less than Alternative A, with annual releases of 8.23 maf (average of 71.4% of years), and 1 year more than Alternative A, with annual releases greater than 8.23 maf in an average of 28.6% of years. Because of the lower October through December release volume, it is possible that the higher elevation would result in Lake Powell operating in a higher operating tier. This is depicted in Figure 4.2-8, which shows at least one trace that operates in the Upper Elevation Balancing Tier instead of the Mid-Elevation Release Tier as compared to Alternative A (shown as a decrease in the Mid-Elevation Release 75th percentile and a corresponding increase in the Upper Elevation Balancing median relative to Alternative A).

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alternative C, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative C, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, with an average of 0.2 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual releases extending beyond the water year also would be less than under Alternative A, with an average volume of 107 kaf and a range from 0 to 1,210 kaf.

Under Alternative C, monthly release volumes in July through November would be lower than under Alternative A. Release volumes from December through August are higher than those under Alternative A. In years when HFEs would be implemented under Alternative C, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative C, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. On the basis of release temperatures and the ability to achieve target downstream temperatures, experimental low summer flows would be implemented on average 1.8 times per 20-year trace, with a range from zero to four per trace.

Modeling of experimental low summer flows showed that Alternative C would not affect the operating tier. The modeling of low summer flows also showed a slight potential for increases in annual releases extending beyond the water year; however, they would be operationally modified to help ensure that did not occur.

Lake Powell end-of-December elevations under Alternative C would tend to be slightly higher than those under Alternative A. Under Alternative C, the median elevation for Lake Powell at the end of December was about 3,630 ft, and on average 1.5 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles, respectively. Under Alternative C, end-of-December elevations at the 10th percentile were on average 0.7 ft higher than those under Alternative A, and on average 1.0 ft higher than those at the 90th percentile under Alternative A. Under Alternative C, the percentage of traces below minimum power pool would be identical to those under Alternative A.

Lake Mead end-of-December elevations under Alternative C would tend to be slightly lower than those under Alternative A. Under Alternative C, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 0.6 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative C, elevations at the 10th percentile were on average 2.9 ft lower than Alternative A, with a maximum difference of 10 ft. Elevations at the 90th percentile were on average 3.2 ft lower than those under Alternative A. Under Alternative C, the percentage of traces with Lower Basin Shortages are sometimes 5% higher and sometimes 5% lower than under Alternative A; however, the general trend and range of traces with shortages are similar to Alternative A, ranging from 0 for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year simulation.

Compared to Alternative A, mean monthly volume under Alternative C would be higher (by 82,000 to157,000 ac-ft) from February through May, and lower (by 111,000 to 200,000 ac-ft) in August through October; volume would be comparable to that under Alternative A in other months (Figure 4.2-2). The pattern of monthly volumes results from targeted lower volumes in August through October to conserve sand input from the Paria River during the monsoon period. Volume in high-demand months would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 490,000 to 1,100,000 ac-ft in other months.

Mean daily flows under Alternative C would follow the same pattern as monthly volume and would be higher (by 1,300 to 2,500 cfs) than under Alternative A from February through May, and lower (by 1,800 to 3,300 cfs) in August through October; mean daily flow would be comparable to that under Alternative A in other months (Figure 4.2-3).

Under Alternative C, the allowable daily change is lower than under Alternative A, but is proportional to monthly volume (Chapter 2). Mean daily change would be lower than under Alternative A in all months and would range from 1,300 to 6,200 cfs (Figure 4.2-4).

Under Alternative C, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 5.8°C (11.7–17.6°C) difference, notwithstanding the effect of low summer flows. Spring temperatures would warm around 3.8°C (9.4–13.2°C), and fall temperatures would warm about 3.6°C (12.3–15.9°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative C vary less than ±0.4°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative C, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low and would be localized and temporary.

In summary, compared to Alternative A, Alternative C would result in some change from current conditions related to reservoir elevations, annual operating tiers, monthly release volumes, and mean daily flows, but it would result in lower mean daily changes in flow throughout the year. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.4 Alternative D (Preferred Alternative)

Alternative D would show little or no difference from Alternative A with regard to operating tier. Alternative D does not result in different operating tiers than Alternative A in any year, in any trace, because the October through December release volumes would be identical to those under Alternative A.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative D, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of modeled annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative D, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, with an average of 0.4 years per trace, and a range from zero to two occurrences per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 146 kaf and a range from 0 to 1,495 kaf.

In years without experimental low summer flows, the monthly release volumes under Alternative D would be fairly constant throughout the year, the most constant of all alternatives except Alternative G. In the years when HFEs would be implemented under Alternative D, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative D, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. Under Alternative D, experimental low summer flows would be implemented only during the second 10 years of the LTEMP period, and would use the implementation processes described in Sections 2.2.4.3, 2.2.4.4, and 2.2.4.6. On the basis of release temperatures and the ability to achieve target downstream temperatures, these would take place on average 0.7 times per 20-year trace, with a range of zero to three per trace.

Lake Powell end-of-December elevations under Alternative D would be nearly indistinguishable from those under Alternative A. Under Alternative D, the median elevation for Lake Powell at the end of December would be about 3,630 ft, on average 0.2 ft higher than under Alternative A throughout the 20-year LTEMP period. Near the beginning of the period, end-of-December elevations ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative D, end-of-December elevations were on average 0.2 and 0.1 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative D, this modeling showed 3 years out of 420 years (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490-ft minimum power pool. This is one more year than under Alternative A and is a result of Alternative D releasing 151 kaf more than Alternative A in the October through March (the typical low elevation month) period in an 8.23-maf release year.

Lake Mead end-of-December elevations under Alternative D would be very similar to those under Alternative A. Under Alternative D, the median elevation for Lake Mead at the end of December was on average the same as Alternative A: about 1,100 ft near the beginning of the period and about 1,080 ft near the end of the period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative D, elevations were on average 0.7 and 0.4 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Under Alternative D, implementation of low summer flows would result in one additional trace in shortage in 2025 compared with Alternative A (1 year out of 420 years total). Otherwise, the general trend and range of traces with shortages are the same as under Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year period.

Modeling of experimental low summer flows and macroinvertebrate production flows showed that Alternative D would not affect the operating tier. The modeling of low summer flows also showed a slight potential for increases in annual releases extending beyond the water year; however, they would be operationally modified to help ensure that did not occur.

Compared to Alternative A, mean monthly volume under Alternative D would be higher (by 43,000 to 98,000 ac-ft) in October, November, February, March, and April, and lower (by 60,000 to 127,000 ac-ft) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly volumes approximates that of Western Area Power Administration's (WAPA's) contract rate of delivery. Volume in high-demand months would range from approximately 640,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 620,000 to 1,200,000 ac-ft in other months. Note that adjustments made to Alternative D after modeling was complete resulted in a 50-kaf increase in August (changed from 750 to 800 kaf) and a corresponding 25-kaf decrease in May and June (changed from 657 to 632 kaf and 688 to 663 kaf, respectively) in an 8.23-maf year.

Mean daily flows under Alternative D would follow the same pattern as monthly volume and would be higher (by 700 to 3,000 cfs) than Alternative A in October, November, February, March, and April, and lower (by 1,000 to 2,100 cfs) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-3).

Under Alternative D, the allowable daily change would be proportional to monthly volume (Section 2.2.4). Mean daily change would be slightly higher than that under Alternative A in October through June, but the same or less in July through August. Mean daily change would range from about 2,700 to 7,600 cfs (Figure 4.2-4).

Under Alternative D, mean winter temperatures are expected to warm the least, with a difference of about 0.6°C (10.0–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.0°C (11.6–17.5°C) difference, notwithstanding the effect of low summer flows. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative D vary less than ±0.3°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative D, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative D would result in negligible changes from current conditions related to reservoir elevations, no change in annual operating tiers, more even monthly release volumes and mean daily flows, and lower mean daily changes in flow. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.5 Alternative E

Alternative E would show little or no difference from Alternative A with regard to operating tier. Alternative E does not result in different operating tiers than Alternative A in any year, in any trace, because the October through December release volumes would be identical to those under Alternative A.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative E, more water would be released in the earlier months of water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative E, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than Alternative A, with an average of 0.2 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 109 kaf and a range from 0 to 1,022 kaf.

In years without experimental low summer flows, the monthly releases volumes under Alternative E would be fairly constant throughout the year and comparable to Alternative D. In years when HFEs would be implemented under Alternative E, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative E, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. On the basis of release temperatures and the ability to achieve target downstream temperatures, experimental low summer flows would be implemented on average 1.5 times per 20-year trace, with a range from zero to four per trace.

Lake Powell end-of-December elevations under Alternative E would be very similar to those under Alternative A. Under Alternative E, the median elevation for Lake Powell at the end of December was about 3,630 ft, and on average 0.3 ft higherthan under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative E, end-of-December elevations were on average 0.2 and 0.3 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative E, this modeling showed 3 years out of 420 years (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490 ft minimum power pool. This is one more year than under Alternative A. This is a result of Alternative E releasing 203 kaf more than Alternative A in the October through March (the typical low elevation month) period in an 8.23-maf release year.

Lake Mead end-of-December elevations under Alternative E would be very similar to those under Alternative A. Under Alternative E, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 0.1 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative E, elevations throughout the period averaged 0.9 and 0.7 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Under Alternative E, implementation of low summer flows would result in one additional trace in shortage in 2020 compared with Alternative A (1 year out of 420 years total) and one fewer trace in 2022. Otherwise, the general trend and range of traces with shortages are the same as under Alternative A, starting at zero for the first 2 years of the model period, then increasing to 62% of traces near the end of the 20-year period.

Implementation of experimental low summer flows under Alternative E would not affect the operating tier, but slight differences could result for volumes of annual release extending beyond the water year and end-of-year elevations at Lake Powell and Lake Mead; however, they would be operationally modified to ensure that did not occur.

Compared to Alternative A, mean monthly volume under Alternative E would be higher (by 45,000 to 128,000) in October, November, February, March, and April, and lower (by 30,000 to 242,000 ac-ft) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly volumes follows WAPA's contract rate of delivery, but it is lower in August and September to target lower volumes in August through October to conserve sand input from the Paria River during the monsoon period. Volume in high-demand months would range from approximately 660,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 580,000 to 1,100,000 ac-ft in other months.

Mean daily flows under Alternative E would follow the same pattern as monthly volume and would be higher (by 700 to 2,100 cfs) than Alternative A in October, November, February, March, and April, and lower in (by 500 to 4,000 cfs) December, January, July, August, and September; volumes would be comparable to those under Alternative A in May and June (Figure 4.2-3).

Under Alternative E, the allowable daily change would be proportional to monthly volume (Chapter 2), and higher than under Alternative A, in all months but September and October (lower in these two months). Mean daily change would range from 1,100 to 9,600 cfs (Figure 4.2-4).

Under Alternative E, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.0°C (11.6–17.6°C) difference, notwithstanding the effect of low summer flows. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative E vary less than ±0.4°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative E, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative E would result in negligible change from current conditions related to reservoir elevations, no change in annual operating tiers, more even monthly release volumes and mean daily flows, and higher mean daily changes in flow. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.6 Alternative F

Alternative F would show the greatest differences from Alternative A with regard to operating tier of all the alternatives. The October-through-December release volume for Alternative F is 534 kaf less than Alternative A in an 8.23-maf year; this difference could result in a slightly higher end-of-December Lake Powell elevation, and sometimes a different operating tier. Alternative F would result in a different operating tier from that under Alternative A in 2.1% of years.

Alternative F would result in fewer instances of the Mid-Elevation Release Tier (decrease of 2.2% of years on average) and more instances of the Upper Elevation Balancing and Equalization Tiers (increase of 1.1% of years on average for both tiers). During the interim period (through 2026), Alternative F would operate at times within each of the four operating tiers at the following mean annual frequencies: Upper Elevation Balancing Tier—47.3%; Equalization Tier—38.5%; Mid-Elevation Release Tier—13.2%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative F has annual releases of 8.23 maf in an average of 72.1% of years and annual releases greater than 8.23 maf in an average of 27.9% of years.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative F, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of modeled annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative F, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, and the lowest of all the alternatives with an average of 0.1 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual release extending beyond the water year is also less than under Alternative A, and the lowest of all alternatives with an average volume of 69 kaf and a range of 0 to 1,135 kaf.

Under Alternative F, monthly release volumes follow a more natural hydrograph pattern than other alternatives, with the highest flows in the spring months April through June and lower flows in the remaining months. Release volumes in December through August are significantly lower than those under Alternative A. When HFEs would be implemented under Alternative F, water would be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell end-of-December elevations under Alternative F would be higher than those under Alternative A; this would be the largest difference of all the alternatives. Under Alternative F, the median elevation for Lake Powell at the end of December was about 3,630 ft, on average 3.2 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,565 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,565 ft to about 3,680 ft near the end of the period. Under Alternative F, end-of-December elevations were on average 5.1 and 1.8 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative F, this modeling showed there would be no occurrences of Lake Powell elevations dropping below the minimum power pool.

Lake Mead end-of-December elevations under Alternative F would be lower than those under Alternative A. Under Alternative F, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 2.9 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative F, elevations throughout the period were on average 4.0 and 2.3 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Near the end of the period, however, elevations under Alternative F were up to 12.5 ft lower than those under Alternative A at the 10th percentile. Under Alternative F, the percentage of traces with Lower Basin Shortages would be higher than that under Alternative A in nearly all years, with differences ranging from 0 to 10% higher than under Alternative A. However, the general trend and range of traces with shortages are the same as under Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year period.

Compared to Alternative A, mean monthly volume under Alternative F would be much higher (by 439,000 to 651,000 ac-ft) in April, May, and June, but much lower (by 214,000 to 433,00 ac-ft) in December, January, July, August, and September (Figure 4.2-2). This monthly pattern is intended to more closely match a natural hydrograph with high spring flows and low summer through winter flows. Volume in high-demand months would range from approximately 430,000 to 1,700,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 440,000 to 1,500,000 ac-ft in other months.

Mean daily flows under Alternative F would follow the same pattern as monthly volume and would be much higher (by 7,400 to 10,600 cfs) in April, May, and June, but much lower (by 3,600 to 7,000 cfs) in December, January, July, August, and September (Figure 4.2-3).

Under Alternative F, flow typically would not change within days except to ramp up and down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

Under Alternative F, mean winter temperatures (Table 4.2-2) are expected to warm the least, with a difference of about 0.6°C (9.9–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.8°C (11.9–18.6°C) difference. Spring temperatures would warm around 3.0°C (9.5–12.5°C), and fall temperatures would warm about 3.7°C (12.3–16.0°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative F are different than those under Alternative A in the spring and summer seasons. In the spring, the downstream temperature difference at Diamond Creek would be approximately 1.1°C cooler than that for Alternative A. This is likely due to the fact that this alternative has much higher average spring releases, so larger volumes of seasonally cooler Lake Powell water are released downstream (Vernieu et al. 2005; Reclamation 2011b) than in any of the other LTEMP alternatives. In addition, Alternative F features a total of 22 high flows (both sediment-triggered HFEs and other high-flow events) in the spring, which may add to the overall downstream cooling effect.

For the summer period, the downstream mean temperature at Diamond Creek would be approximately 1.4°C warmer than that under Alternative A. This warming is a result of much lower summer flows associated with Alternative F compared to all of the other LTEMP alternatives. These lower flows allow for a larger surface-area-to-volume ratio and greater exposure time with the warmer summer ambient air, which facilitates downstream warming (Vernieu et al. 2005).

Under Alternative F, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from annual low steady flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternatives A, B, C, D, and E; however, the probability is still considered very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative F would result in some change from current conditions related to reservoir elevations and annual operating tiers, large changes in monthly release volumes and mean daily flows, and steady flows throughout the year. Compared to Alternative A and the other alternatives, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.7 Alternative G

Alternative G is expected to show little or no difference from Alternative A with regard to operating tier. The October through December release volume for Alternative G is 75 kaf more than Alternative A in an 8.23-maf year; this difference could result in a slightly lower end-of-December Lake Powell elevation and sometimes a different operating tier. Alternative G would result in a different operating tier from that under Alternative A in 0.7% of years.

The frequency of operating tiers under Alternative G would be identical to that under Alternative A during the interim period (through 2026) and nearly the same as Alternative A after the interim period. After the interim period, Alternative G would have at least one trace with fewer annual releases of 8.23 maf (average of 71.4% of years) than Alternative A and at least one trace with more annual releases greater than 8.23 maf (average of 28.6% of years) than Alternative A.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative G, more water would be released than under Alternative A in the earlier months of the water year; therefore, Alternative G would not result in as many instances of modeled annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative G, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A with an average of 0.5 years per trace, and a range from zero to two occurrences per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 151 kaf and a range from 0 to 1,440 kaf.

Under Alternative G, monthly release volumes are as constant as possible, given hydrologic uncertainty throughout the water year. Release volumes during December through August are slightly higher than those under Alternative A. In years when HFEs would be implemented under Alternative G, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell end-of-December elevations under Alternative G would tend to be slightly lower than those under Alternative A. Under Alternative G, the median elevation for Lake Powell at the end of December would be nearly the same as under Alternative A (about 3,630 ft), and on average 0.4 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative G, end-of-December elevations were on average 1.2 and 0.3 ft lower than those at the 10th and 90th percentiles, respectively, under Alternative A. Under Alternative G, there are two occurrences of Lake Powell below the minimum power pool, the same as under Alternative A.

Lake Mead end-of-December elevations for Alternative G would tend to be slightly higher than those under Alternative A. Under Alternative G, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 1.4 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about

1,010 ft to about 1,210 ft near the end of the period. Under Alternative G, elevations at the 10th percentile were sometimes higher and sometimes lower compared to Alternative A, with differences ranging from 6.8 ft lower to 4.0 ft higher throughout the 20-year period. Elevations at the 90th percentile were nearly identical to those under Alternative A (the maximum difference in any year was 1.0 ft). Under Alternative G, there was one fewer trace in shortage in 2017 compared to Alternative A (1 year out of 420 years total) and one more trace in 2020. Otherwise, the general trend and range of traces with shortage are the same as under Alternative A, starting at zero for the first 2 years of the model run, then increasing to 62% of traces near the end of the 20-year period.

Compared to Alternative A, mean monthly volume under Alternative G would be higher (by 71,000 to 286,000 ac-ft) in October, November, March, and April, but lower (by 139,000 to 196,000 ac-ft) in December, January, July, and August (Figure 4.2-2). The monthly pattern for Alternative G is approximately equal to monthly volumes throughout the year, except for adjustments due to changes in forecast. Volume in high-demand months would range from approximately 60,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 600,000 to 1,300,000 ac-ft in other months.

Mean daily flows under Alternative G would follow the same pattern as monthly volume and would be higher (by 1,200 to 4,800 cfs) in October, November, March, and April, but lower (by 2,300 to 3,200 cfs) in December, January, July, and August (Figure 4.2-3).

Under Alternative G, flow typically would not change within days except to ramp up and down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

Under Alternative G, mean winter temperatures are expected to warm the least, with a difference of about 0.6°C (10.0–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.2°C (11.6–17.8°C) difference. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 2.9°C (12.4–15.3°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative G are slightly warmer than those under Alternative A in the summer season (temperature difference at Diamond Creek is approximately 0.6°C warmer than under Alternative A). As under Alternative F, this summer warming is likely a result of the lower summer flows compared to those of Alternative A, which would facilitate downstream warming (Vernieu et al. 2005). The degree of warming is less than that observed under Alternative F, because summer flows associated with Alternative G are somewhat higher in comparison.

Under Alternative G, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from year-round steady flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternatives A, B, C, D, and E, but is still considered very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative G would result in negligible change from current conditions related to reservoir elevations and annual operating tiers, and even monthly release volumes and mean daily flows, and steady flows throughout the year. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.3 SEDIMENT RESOURCES

Issue: How do alternatives affect sediment resources in the project area?

Impact Indicators:

- The amount of sand transported during high flows relative to total sand transport
- Sand mass balance in Marble Canyon
- The size and position of the Colorado River delta in Lake Mead

This section presents an analysis of impacts on sediment resources of the Colorado River corridor between Glen Canyon Dam and Lake Mead, and inflow deltas in Lake Mead. Sediment resources include sandbars, beaches, and lake deltas. Sediment is one of the fundamental components of the ecosystem along the river corridor in Glen and Grand Canyons. The dynamics considered are the building and erosion of sandbars and beaches as well as the sediment remaining in the river channel, in the river corridor below the dam. The sediment objective, as stated in Section 1.4, is to “increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.” This section evaluates alternatives against this objective.

Quantitative analysis using a set of numerical models was conducted for the Colorado River from Lees Ferry (RM 0) to Phantom Ranch (RM 87). Because a quantitative model is only available from Lees Ferry to RM 87, impact assessments for the Colorado River corridor upstream of Lees Ferry, downstream of RM 87, and for lake deltas are more qualitative in nature but were considered sufficient to assess these impacts.

There are two generally opposing processes related to sediment resources downstream of Glen Canyon Dam: (1) sediment deposition in sandbars at elevations above the range of normal flows and (2) retention of sediment within a reach of the river. Because of the limited sand supply, the flows needed to achieve the first objective (e.g., building high-elevation sandbars) reduce the amount of sand retained on the riverbed within a reach. Using dam operations, it is not possible to build high-elevation sandbars without transporting sand out of the reach.

Operations at Glen Canyon Dam directly affect sediment resources via changes in releases and corresponding downstream flows and changes in reservoir elevation in Lakes Powell and Mead. These changes can occur on hourly, daily, monthly, and annual timescales. Changes in river flow result in changes in sandbar sediment storage and riverbed sand storage. Aspects of operations and river flow that affect sediment resources are related to the monthly distribution of annual release volumes, daily fluctuations, and the frequency, magnitude, and duration of HFEs, TMFs, and proactive spring HFEs. This section analyzes the impacts of LTEMP alternatives on these resources for the 20-year LTEMP period.

4.3.1 Analysis Methods

Sediment resources, such as sandbars and riverbed sand, are linked to flow and to each other, just as most other resources discussed in this EIS are linked to sediment.

Impacts were analyzed on the basis of the following categories of information, which are further explained below:

- Records of river stage, streamflow, and sediment discharge at USGS gaging stations along the river and on principal sediment-producing tributaries;
- Sandbar measurements made by Northern Arizona University;
- Published journal articles; and
- Results from the modified Sand Budget Model.

Sandbar deposits (and sandbar-dependent resources such as camping beaches and some archaeological sites) are affected by the amount of riverbed sand transported under a given alternative. A long-term net loss of riverbed sand would result in long-term loss in the number and size of sandbars, with corresponding changes in aquatic and riparian habitat (Reclamation 1995). Changes in sandbar and riverbed sand depend primarily on tributary sand supply; the magnitude, frequency, and duration of HFEs; and the magnitude of daily powerplant fluctuations. Because very little of the sediment input to Lake Powell is released from Glen Canyon Dam, and there is little sediment input between the dam and the confluence with the Paria River, high releases contain very little sediment until after they pass through the Glen Canyon reach.

Currently, there is no available model that can predict sandbar response to differing flow release volumes and patterns. It has been established, however, that “large eddy sandbars form when suspended-sediment loads are transported in high concentrations by the main flow. High sandbars are constructed by large magnitude floods that rise to relatively high elevations” (Schmidt and Grams 2011a). Thus, having high flows that are rich in suspended sediment provide the means for potential sandbar growth.

Because a model is not available to simulate reach-wide sandbar response to dam operations, an indicator of sandbar building was developed that represents the conditions necessary for sandbar deposition (high flows rich in suspended sediment). The potential for building sandbars was estimated using the sand load index, which is a comparison of the mass of sand transported at river flows ≥31,500 cfs relative to the total mass of sand transported at all flows (Figure 4.3-1). The index varies from 0 (no sand transported at flows ≥31,500 cfs) to 1 (all sand transported at flows ≥31,500 cfs); the larger the sand load index for an alternative, the more

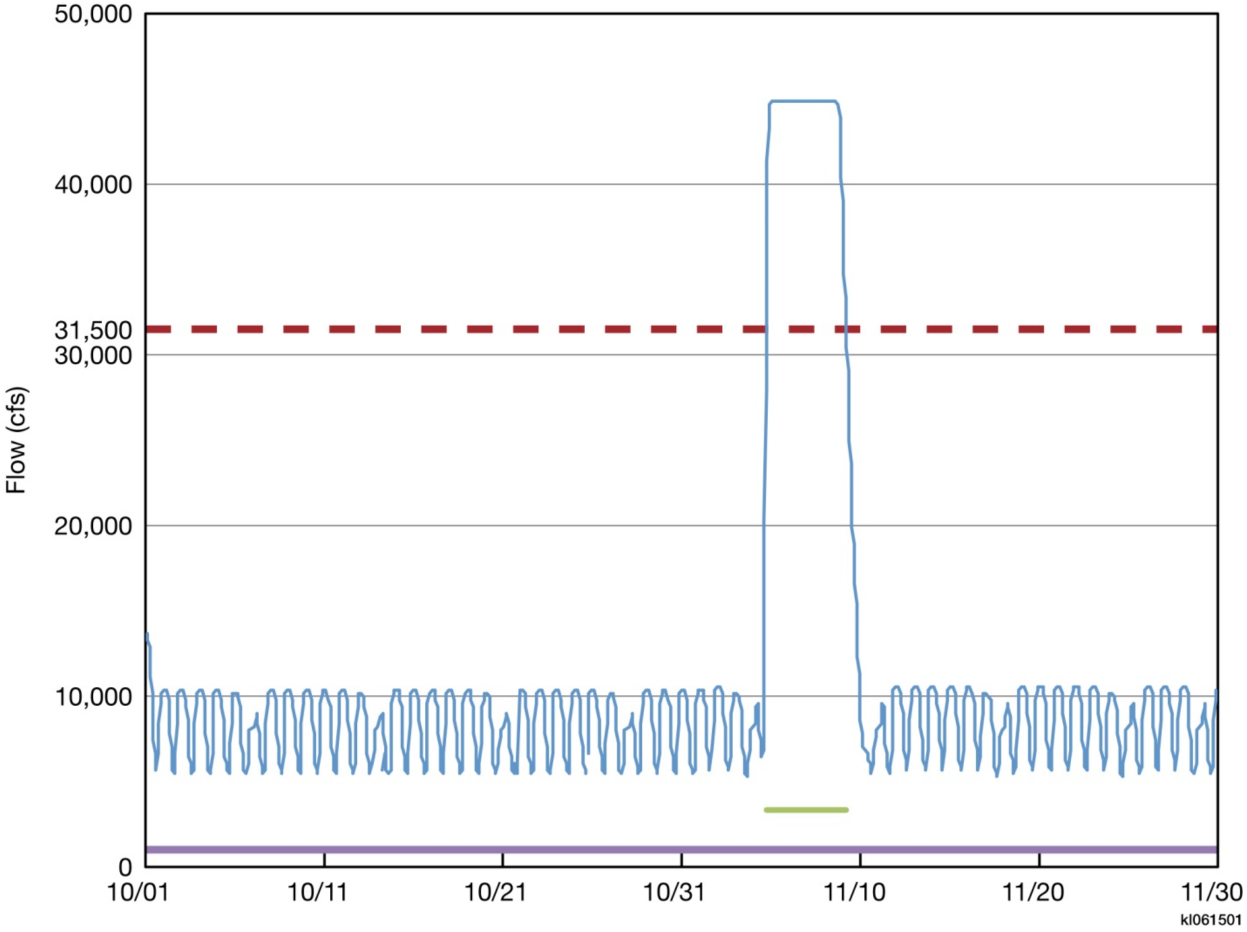

FIGURE 4.3-1 Conceptual Depiction of the Sand Load Index (The blue line is the time series of river flow, and the dashed red line is the threshold condition of 31,500 cfs. The green lines represent the amount of time during which river flow is ≥31,500 cfs. The purple line represents the entire time period of interest. The sand load index is the amount of sand that is transported during the time represented by the green line, relative to the amount of sand transported during the time represented by the purple line.)

potential there is for bar growth (Appendix E). The sand load index only estimates the potential for (and not actual) bar growth, because all sandbars have a maximum potential deposition volume; the closer any given bar is to full, the less deposition will occur (Wiele and Torizzo 2005). The sand load index does not address fully the erosion of sandbars from intervening flows between HFEs.

The increase in potential sandbar growth necessarily increases the mass of sand that moves downstream, decreasing the sand budget. That is, having a high potential for bar growth (resulting from a high sand load index) causes a decrease in the amount of sand on the riverbed, and having a low potential for bar growth (resulting from a low sand load index) allows for more sand to be retained on the riverbed. The measure of sand budget used in this analysis is the sand mass balance index (Figure 4.3-2) calculated for Marble Canyon (RM 0 to RM 61); it is the estimated mass of sand remaining at the end of the 20-year LTEMP period relative to the sand

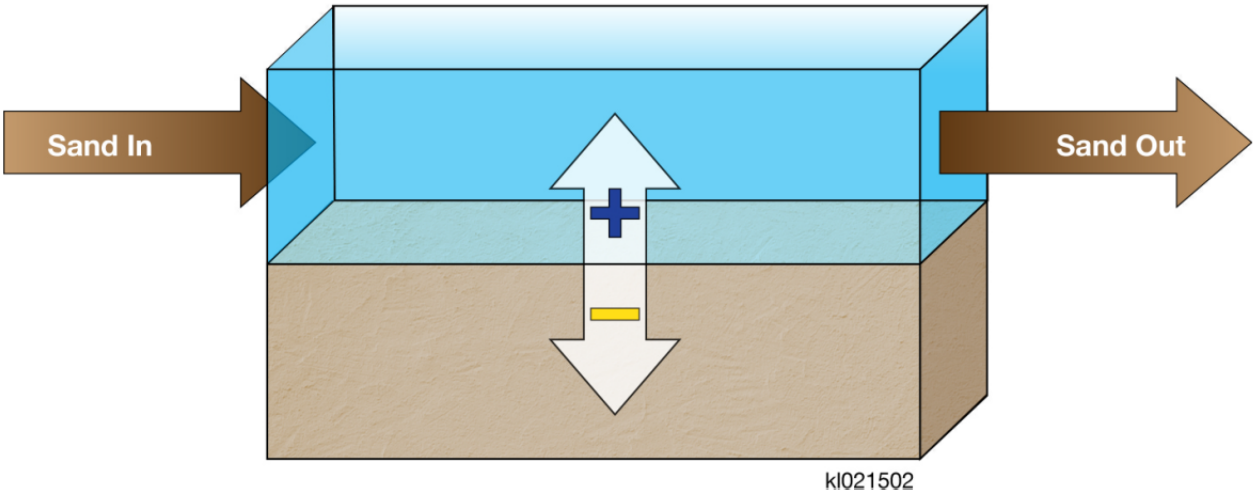

FIGURE 4.3-2 Conceptual Depiction of the Sand Mass Balance Model (The large rectangular solid is a control volume [lower half sand bed and upper half water]. Water and sand are flowing in from the left and out to the right. Purple plus symbol represents the case of a positive sand mass balance where there is an increase in sand thickness due to the "sand in" value being greater than the "sand out" value for a given time period. The yellow minus sign represents the case of a negative sand mass balance, where there is a decrease in sand thickness due to the sand out value being greater than the sand in value for a given time period.)

mass at the start of the period. Data used to calculate the sand mass balance index and the sand load index come from Sand Budget Model outputs.

The Sand Budget Model (Wright et al. 2010; Russell and Huang 2010) is a numerical model that tracks sand storage and transport from Lees Ferry (RM 0) to Phantom Ranch (RM 87). The Sand Budget Model was modified for the purpose of analyzing the impacts of LTEMP alternatives on the sand budget in Marble Canyon (Appendix E). The Sand Budget Model uses empirically based rating curves to compute the sand budget in three reaches; RM 0 to RM 30, RM 30 to RM 61, and RM 61 to RM 87. Modifications to the Sand Budget Model that were implemented for the purposes of the analysis in this EIS include (1) determining when HFEs would be triggered, (2) reallocation of monthly water volumes (less water released in months without HFEs to accommodate HFE water release volume in months with HFEs), and (3) implementation of a trout recruitment model provided by fish subject matter experts to identify years when TMFs would be triggered (Section 4.5).

Potential future sediment delivery from the Paria River can affect results from the modified Sand Budget Model. The mean and median annual sand load from the Paria River for the approximately 50-year time period from October 1, 1963, to January 1, 2014, is approximately 761,000 metric tons and 756,000 metric tons, respectively (Topping 2014; GCMRC 2015b). Three different time series of sediment load for the Paria River were considered to account for uncertainty (Appendix E), with the mean annual input ranging from 648,000 metric tons to 918,000 metric tons. The three 20-year time series selected approximate the 10, 50, and 90% exceedance probabilities, as well as represent the entire historical sediment record explicitly.

Each alternative was modeled in the modified Sand Budget Model with 21 different potential hydrology scenarios (Section 4.1) and three different potential Paria River sediment loads (Section 4.3.1 and Appendix E) to account for uncertainty in future conditions. Comparisons between alternatives are made using the average of these 63 combinations of simulations per alternative, and confidence in the comparisons can be found by considering the inter-quartile range of the 63 simulations. The inter-quartile range indicates that 50% of the estimated values fall within this range, 25% of the values are below this range, and 25% are above this range.

The output of the Sand Budget Model includes the hourly time series of both the mass of sand transported at the downstream boundary of each reach and the sand budget (sand in minus sand out) for each of the three reaches (Figure 4.3-2). Both of these time series are used in the assessment of impacts on sediment resources.

Impacts on sediment resources in the Grand Canyon upstream of RM 87, as analyzed here, are considered in general to be indicative of impacts further downstream, although the timing and magnitude of effects may be different. A quantitative assessment of the alternatives on the sediment resource downstream of RM 87 has not been made, but the literature suggests that the relative rankings of the alternatives would be maintained for downstream reaches (Hazel et al. 2010; Grams et al. 2015).

Lake deltas can be described by their size, which is directly affected by the amount of sand delivered to the delta, and by longitudinal position in a canyon, which is directly affected by reservoir elevation.

The position of the Lake Powell deltas, which occur at the inflows of both the mainstem Colorado River and its tributaries, is dictated by the water surface elevation of Lake Powell.

The size of any given delta on Lake Powell, whether it is the mainstem Colorado River or the tributaries, will not be affected by Glen Canyon Dam operations because operations cannot affect the amount of sediment being delivered to the upstream deltas.

The positions of the Lake Mead deltas, which occur at the inflows of both the mainstem Colorado River and its tributaries, are dictated by the elevation of Lake Mead. Lake Mead elevations are analyzed on a monthly timescale, and the change in elevation from one month to the next depends primarily on the amount of water released from Glen Canyon Dam during that month and the release schedule from Hoover Dam. A lower release volume from Hoover Dam and a higher release volume from Glen Canyon Dam would result in a higher water surface elevation in Lake Mead, causing deltas to form farther up the canyon. The size of Lake Mead's tributary deltas would not be affected by Glen Canyon Dam operations because these operations cannot affect the amount of sediment being delivered to the reservoir's tributary deltas. Glen

Canyon Dam operations can only affect the amount of sediment being delivered to the Colorado River delta in Lake Mead. The sand mass balance results from the modified Sand Budget Model are used to estimate the relative effects of the alternatives on the amounts of sediment that eventually would reach the Colorado River delta in Lake Mead under the alternatives.

4.3.2 Summary of Impacts

General impacts on sandbars, riverbed sand, and lake deltas are discussed below. Specific impacts on these resources are discussed under each alternative in Section 4.3.3. These impacts vary among the alternatives as a result of differences in dam operations, including monthly distribution of annual release volume, within-day fluctuations in releases, and the frequency, magnitude, and duration of high flows, such as sediment-triggered HFEs, TMFs, and proactive spring HFEs. Of these three types of high flows, sediment-triggered HFEs result in the largest impact on sediment resources.

Sandbars are built by high flows. According to Schmidt and Grams (2011a), "the HFE research program demonstrated that eddy sandbars are quickly constructed by high flows if those flows have high suspended-sand concentrations." They also state that "high flows similar in magnitude to those that occurred during the HFEs of 1996, 2004, and 2008 effectively mobilize accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild eddy sandbars in Marble and Grand Canyons" (Schmidt and Grams 2011a). This physical understanding of the process was verified in subsequent high-flow experiments.

Preliminary results indicate that sandbar building occurred in Marble Canyon and the Grand Canyon during each of the fall HFEs conducted in 2012, 2013, and 2014. Sandbars were larger following each HFE at more than half of the 45 long-term monitoring sites (Grams et al. 2015). Immediately following the 2012, 2013, and 2014 HFEs, sandbars were larger at 52%, 52%, and 57% of the monitoring sites, respectively (Grams 2016). Sandbar size did not change substantially at 35% of the monitoring sites following each of the same HFEs. The most recent topographic surveys completed in the fall of 2015 indicated that the total sand volume of the long-term monitoring sandbars increased during the first implementations of the HFE protocol (Grams 2016).

Sandbars erode between HFEs. Erosion rates tend to be highest immediately after a flood (when bars have the most sediment available for erosion), then decrease with time (Grams et al. 2010). Furthermore, "monitoring data show that sandbars erode more quickly as release volumes and daily fluctuations increase, whereas the rate of erosion is reduced when tributary sand inputs continue to occur following sandbar building" (Melis et al. 2011). Steadier flows erode bars at a lower rate than fluctuating flows (Wright, Schmidt et al. 2008).

High flows necessarily export relatively large volumes of sand in order to transfer sand from the riverbed to high-elevation portions of sandbars (Wright, Schmidt et al. 2008). Within-day fluctuations resulting from powerplant operations also increase the amount of sediment that is transported downstream. As noted by Wright and Grams (2010), a steady flow will transport less sand than an equivalent-volume fluctuating flow and retain more sandbars and beaches.

These dynamics are well understood, but the sand load index does not fully address the potential erosion of sandbars from intervening flows.

In order to understand effects on sediment resources, it is necessary to evaluate both the indicators for sandbar growth potential (sand load index) and the indicator for sand budget (sand mass balance index). Both are affected by the number, frequency, and duration of HFEs. During a 20-year period, there are a maximum of 40 possible HFEs (one in the fall and one in the spring each year) if there were sufficient water and sediment volume (see Figure 4.3-5 in Section 4.3.3). Some alternatives limit the maximum number of HFEs that can occur during the 20-year LTEMP period. Alternatives A and B would have the fewest HFEs, because HFEs would not be conducted after 2020 under Alternative A, and HFEs are limited to one every other year under Alternative B; consequently, these alternatives would have the lowest potential for building sandbars as indicated by their relatively low sand load index values. Alternatives F and G would have the most HFEs, highest sand load index values, and greatest potential to build bars. Alternatives C and D would have slightly fewer HFEs than Alternatives F and G, while Alternative E would be a bit lower because spring HFEs would not be implemented in the first 10 years of the LTEMP period. These four alternatives show relatively large improvements in the potential to build sandbars over Alternatives A and B. These differences among alternatives are discussed in greater detail for each alternative in Section 4.3.3.

Alternatives C and E include steady flows associated with HFEs (these steady flows are also referred to as load-following curtailment). Alternative C would implement steady flows before and after a spring HFE and fall HFE. Alternative E would only implement steady flows prior to a fall HFE. Although load-following curtailment does help conserve sediment prior to and after an HFE, the effect is relatively small because of the short duration of the curtailment, and the fact that two other factors reduce sand transport during this time period regardless of curtailment—HFEs reduce the average flow for the remainder of the month, and HFEs are applied in the lowest volume months out of the year.

In contrast to the 277 mi of Marble Canyon and Grand Canyon, the 15-mi Glen Canyon reach of the Colorado River receives very little sediment input. The Glen Canyon reach will continue to be affected by the river during equalization flows, HFEs, or other high-flow events that continue to remove sediment within the reach. Sediment in the Glen Canyon reach is largely a non-renewable resource because the first major sediment-bearing tributary is the Paria River, 16 mi below the dam. As a result, HFEs and other high flows do not generally contribute to the replenishment or retention of beaches within the Glen Canyon reach, and pre-dam beach sediments may continue to be lost.

Annual releases from Glen Canyon Dam affect the transport of sand on the bed of the river as much as, if not more than, alternative-specific dam operations. For all alternatives, years or periods of years that have a relatively low average annual release volume tend to transport less sand, whereas those with higher average annual release volumes tend to transport more sand downstream.

The only delta in Lake Mead that can be affected by LTEMP alternatives in terms of both location and size is the Colorado River delta in Lake Mead; the tributary deltas in Lake Mead will be affected in terms of position by dam operations, but not in terms of size. Using historical data on the GCMRC data portal (GCMRC 2015b), nearly half (approximately 46%) of the suspended sand load reaching the gage at Diamond Creek (RM 225) since October 2002 can be accounted for by suspended sand leaving Marble Canyon (RM 0 to 60). The other half of the suspended sand reaching Diamond Creek comes from tributaries downstream of Marble Canyon, most notably the Little Colorado River. The mass balance across alternatives varies by almost a factor of 3 (Table 4.3-1), but this magnitude of variability is insignificant when compared to both the average amount of sediment leaving Marble Canyon (10,000 kilotons per year) and the average amount of sediment reaching Diamond Creek (22,000 kilotons per year). Therefore the alternatives considered will have minimal impact on the size of the Colorado River delta in Lake Mead.

The position of deltas in Lake Mead is directly affected by reservoir elevation. The elevations of Lake Powell and Lake Mead are more sensitive to future hydrology and corresponding annual releases from Glen Canyon Dam (Section 4.1) than to any alternative. Figures 4.3-3 and 4.3-4 present the minimum, mean, and maximum monthly elevations relative to full pool for 21 different hydrology traces across the seven alternatives. Pool elevations and the effects on deltas are ultimately controlled by regional hydrologic conditions and will be minimally affected by the alternatives. Alternative-specific impacts on reservoir deltas were not further analyzed and are not discussed in Section 4.3.3.

4.3.3 Alternative-Specific Impacts

The impacts of LTEMP alternatives on sediment resources are summarized in Table 4.3-1. Indicators of riverbed sand are mainly derived from modeling, and sandbar indicators are the result of field surveys, modeling, and empirical data. Numerical values, based on sources of information listed in Section 4.3.1, were used as indicators of impacts for all sediment resources. Alternative-specific results for the number of HFEs, sand load index values, and sand mass balance index values are presented in Figures 4.3-5, 4.3-6, and 4.3-7, respectively. Some uncertainty exists in the numerical values shown in these figures, in Table 4.3-1, and in the subsequent discussion of alternatives. In general, however, uncertainty would not affect relative differences among alternatives and would allow a comparison among the alternatives because the uncertainties apply across all alternatives. This uncertainty does mean that very small differences between alternatives may not be meaningful.

TABLE 4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Least HFEs of any alternative; would result in the lowest potential for building sandbars (highest impact of alternatives), and the highest sand mass balance (lowest impact of alternatives)	Compared to Alternative A, sandbar building potential would increase 10%, but higher fluctuations would result in lower sand mass balance (80% decrease)	Compared to Alternative A, sandbar building potential would increase 157%, but sand mass balance would decrease 112%	Compared to Alternative A, sandbar building potential would increase 152%, but sand mass balance would decrease 47%	Compared to Alternative A, sandbar building potential would increase 119%, but sand mass balance would decrease 96%	Compared to Alternative A, sandbar building potential would increase 167%, but sand mass balance would decrease 230% (highest impact of alternatives)	Compared to Alternative A, sandbar building potential would increase 176% (lowest impact of alternatives), but sand mass balance would decrease 182%
High Flow Events							
Average number of HFEs triggered in 20 years	5.5	7.2 (31% increase)	21.3 (287% increase)	21.1 (284% increase)	17.1 (211% increase)	19.3 (38.1)[b] (251% and 593% increase, respectively)	24.5 (345% increase)
Maximum number of HFEs that could be implemented	14	10	40	38	30	40	40
Sandbars							
Sand load index value (20-year value)	0.21	0.23	0.54	0.53	0.46	0.56	0.58
Sand load index, relative to Alternative A (% change)	0%	10% increase	157% increase	152% increase	119% increase	167% increase	176% increase

TABLE 4.3-1 (Cont.)

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Sediment Balance							
Sand mass balance index (kilotons)[c]	–1,010	–1,810	–2,140	–1,480	–1,980	–3,320	–2,840
Sand mass balance index, relative to No Action (% change)	0%	80% decrease	112% decrease	47% decrease	96% decrease	230% decrease	182% decrease
Mean relative to average annual Paria sand load	–1.3	–2.4	–2.8	–2.0	–2.6	–4.4	–3.7
Interquartile range relative to annual Paria sand load	–4.9 to 1.5	–5.2 to 0	–5.3 to –0.6	–3.9 to 0	–5.3 to –0.2	–5.5 to –3.4	–5.9 to –1.8
Lake Mead Delta	The size and the position of the Colorado River Delta in Lake Mead is influenced more by regional hydrology and less by the dam operation alternatives considered in this analysis						

[a] The results presented here are from modeling conducted prior to making several adjustments to Alternative D, including prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE, elimination of experimental load-following curtailment after fall HFEs, and an adjustment in the monthly release volumes, as described in Section 2.2.4. The actual number of HFEs would be about 19.8 (1.3 fewer) and would result in a slightly lower sand load index and higher sand mass balance index. Change in monthly release volumes would result in a slight increase in sediment transport (1.2%), resulting in a lower (not quantified) sand load index and a lower sand mass balance index. Elimination of load-following curtailment would result in a 0.6% decrease in sand mass balance index. See Section 4.1 for more detail.

[b] If alternative-defined annual spring flood (24 hr, 45,000 cfs flow if no sediment-triggered HFE) is counted, there would be a total of 38.1 HFEs.

[c] Sand mass at end of 20-year LTEMP period from RM 0 to 61 relative to start of LTEMP period; negative indicates net loss of sediment.

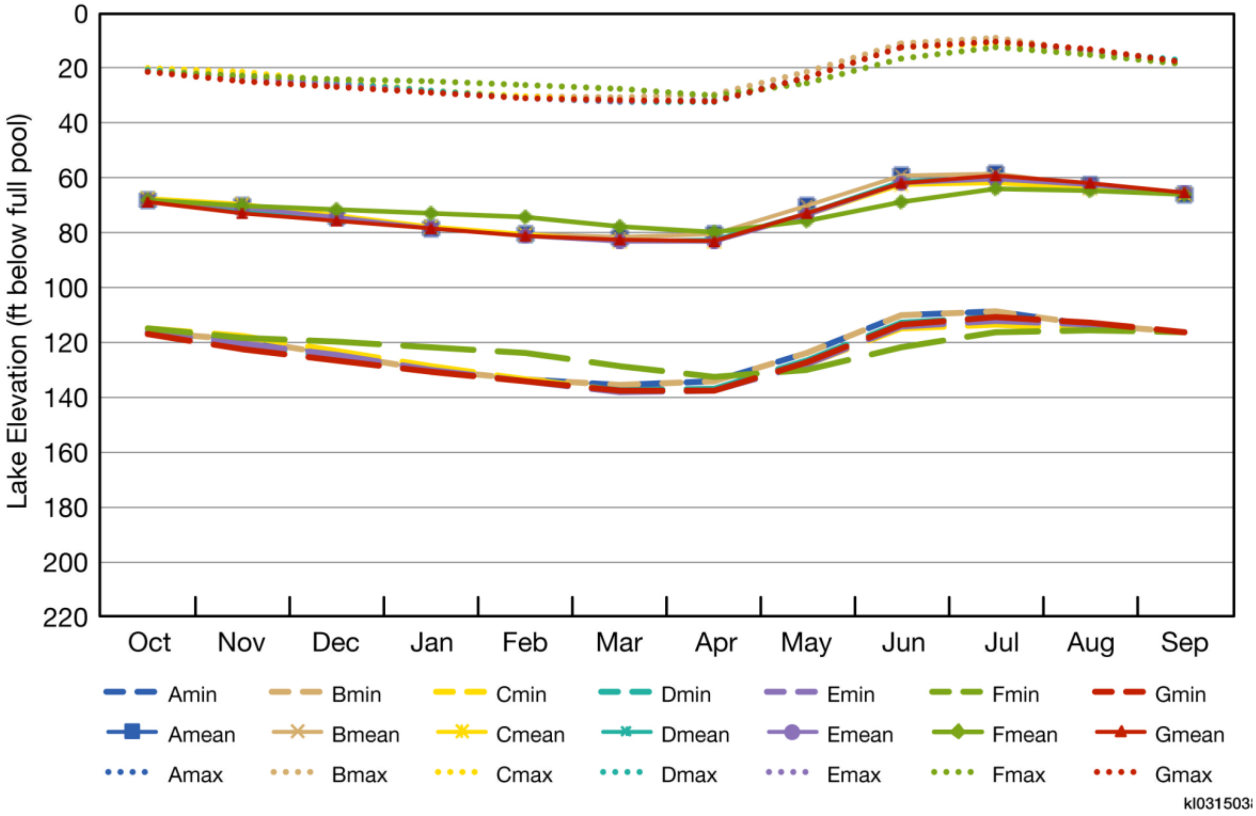

FIGURE 4.3-3 Variation in Lake Powell Pool Elevation Relative to Full (3,700 ft) for 21 Hydrology Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are shown as dashed, solid, and dotted lines, respectively.)

4.3.3.1 Alternative A (No Action Alternative)

Under Alternative A, HFEs would continue only for the period of the current HFE protocol, which will expire in 2020. In addition, spring HFEs would not occur until 2016 at the earliest. Therefore, Alternative A provides for a maximum of 14 HFEs during the 20-year period. On average, across 21 hydrology and 3 sediment time series (63 simulations total), there would be 5.5 HFEs triggered and implemented in the 20-year period (Figure 4.3-5), which is 39% of the maximum possible under Alternative A, and 14% of the overall maximum of 40 (one spring and one fall HFE every year).

The estimated 20-year average sand load index for Alternative A is 0.21, with an interquartile range of 0.17–0.24 (Figure 4.3-6). This indicates that about 20% of the sediment transported over the 20-year LTEMP period is transported when discharge is >31,500 cfs, resulting in potential sandbar building. The sand load index cannot currently be directly compared to sandbar response or size, but this value provides a baseline to which the other alternatives can be compared, and this alternative can be compared to dam operations that have been in place since 2012.

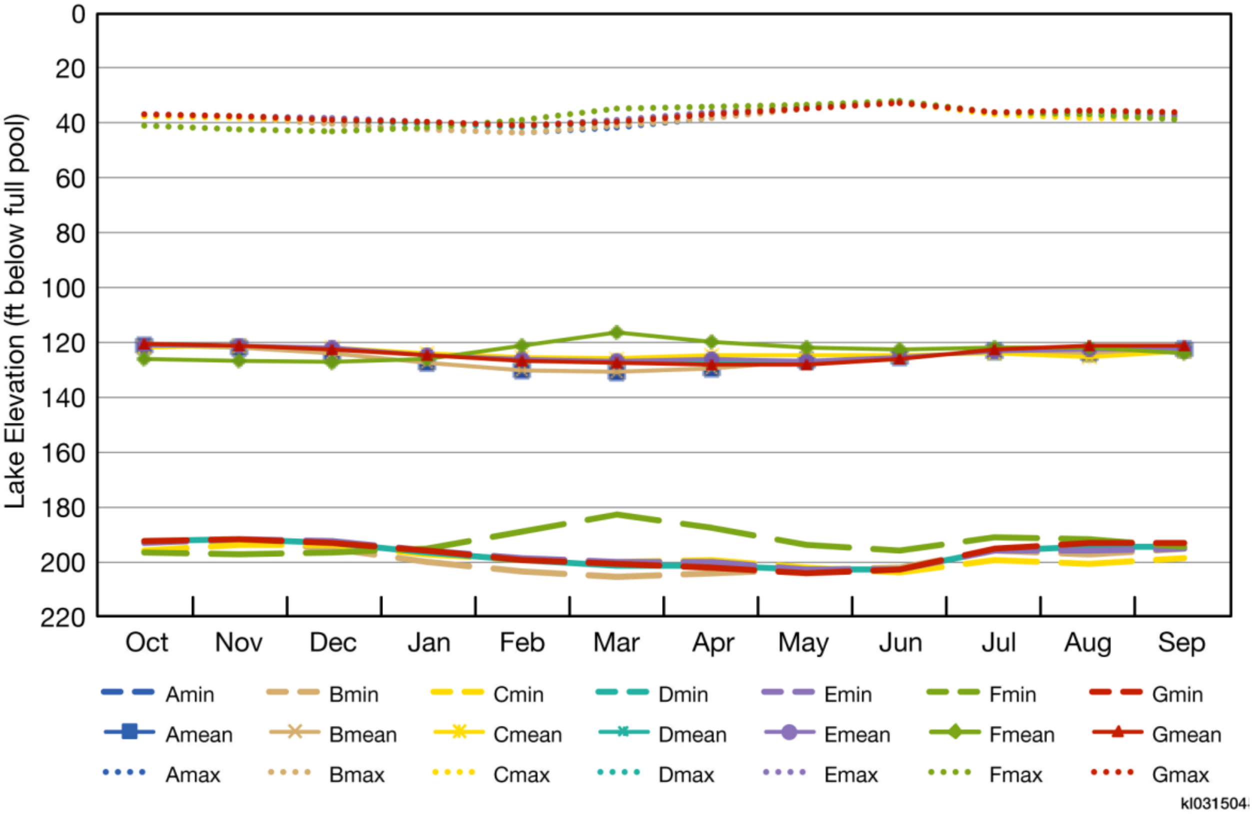

FIGURE 4.3-4 Variation in Lake Mead Pool Elevation Relative to Full (1,229 ft) for 21 Hydrology Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are shown as dashed, solid, and dotted lines, respectively.)

Alternative A is a continuation of the current HFE protocol as defined in the 2011 EA (Reclamation 2011b). Three HFEs have been conducted under the HFE protocol; for these, sandbars increased in both volume and area as they did in response to the three preceding HFEs of 1996, 2004, and 2008 (Grams 2014). The sand load index for Alternative A of 0.21 is the lowest of all alternatives (Table 4.3-1), indicating the lowest potential for building sandbars. This is due to the expiration of the HFE protocol in 2020, which in turn leads to the lowest number of HFEs for the simulation period of all alternatives. It is expected that bar building would continue through the HFE protocol window, and then bars would erode and decrease in size after 2020.

Under Alternative A, there would be an estimated average net loss of 1,010 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 1.3 times the annual average sand input from the Paria River. About 46% of the 63 conditions modeled resulted in a positive sand mass balance. This alternative retains, on average, the most sand in Marble Canyon of any alternative, but, as discussed above, the lowest potential for sandbar building after 2020.

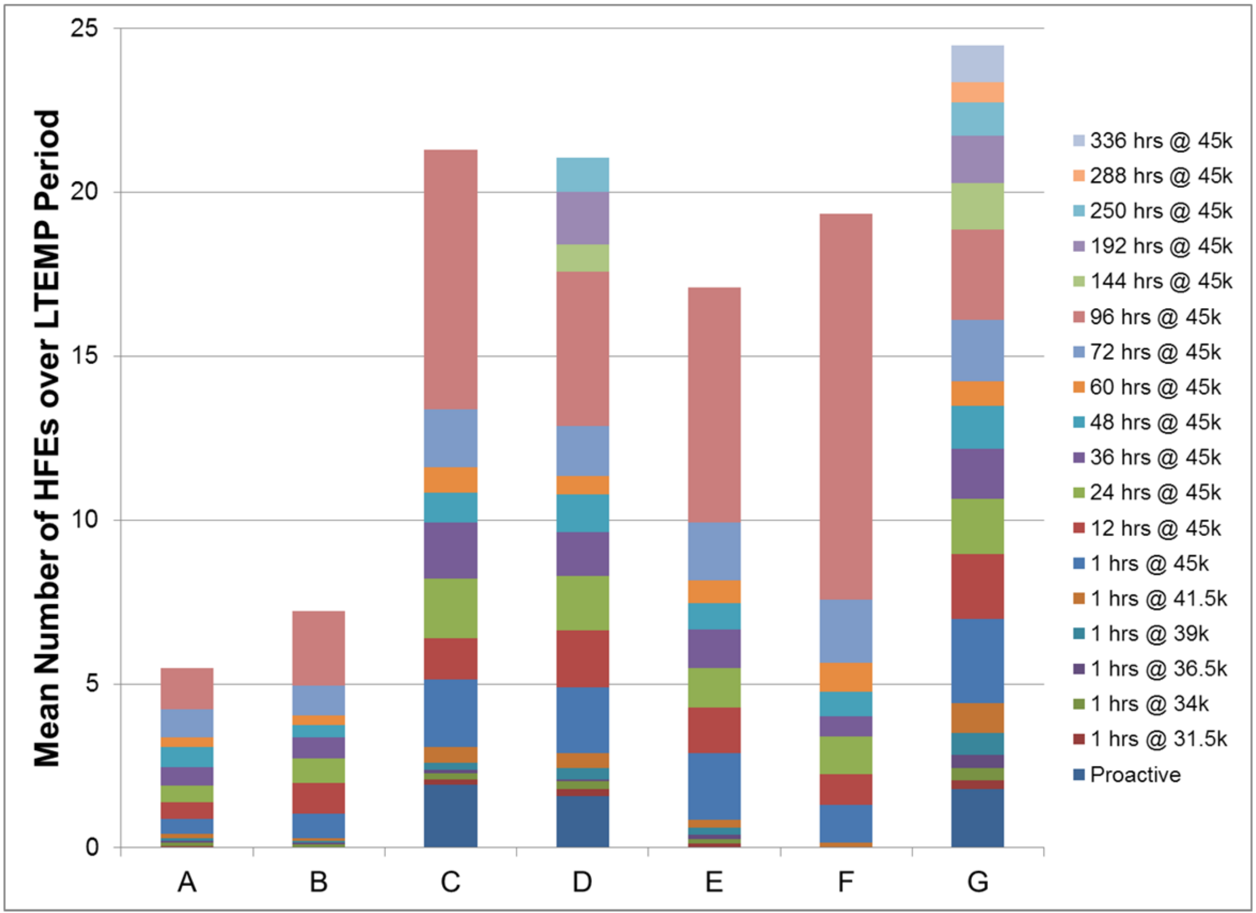

FIGURE 4.3-5 Number and Type of HFEs Expected to Occur during the 20-Year LTEMP Period under the Seven Alternatives

In summary, Alternative A has the least HFEs of any alternative and would result in the highest sand mass balance, but the lowest potential for building sandbars.

4.3.3.2 Alternative B

Under Alternative B, spring and fall HFEs could be implemented during the 20-year LTEMP period, but HFEs would not be implemented more often than once every 2 years. Therefore, Alternative B would allow a maximum of 10 sediment-triggered HFEs during the 20-year LTEMP period. On average, there would be 7.2 HFEs triggered and implemented in the 20-year period (Figure 4.3-5), which is 72% of the maximum possible under the alternative, and 18% of the maximum of 40 possible under other alternatives.

The estimated 20-year average sand load index for Alternative B is 0.23, with an inter-quartile range of 0.20–0.27 (Figure 4.3-6). The estimated average sand load index for Alternative B is 10% greater than the sand load index for Alternative A, suggesting slightly higher bar-building potential under Alternative B. The number of HFEs and the sand load index

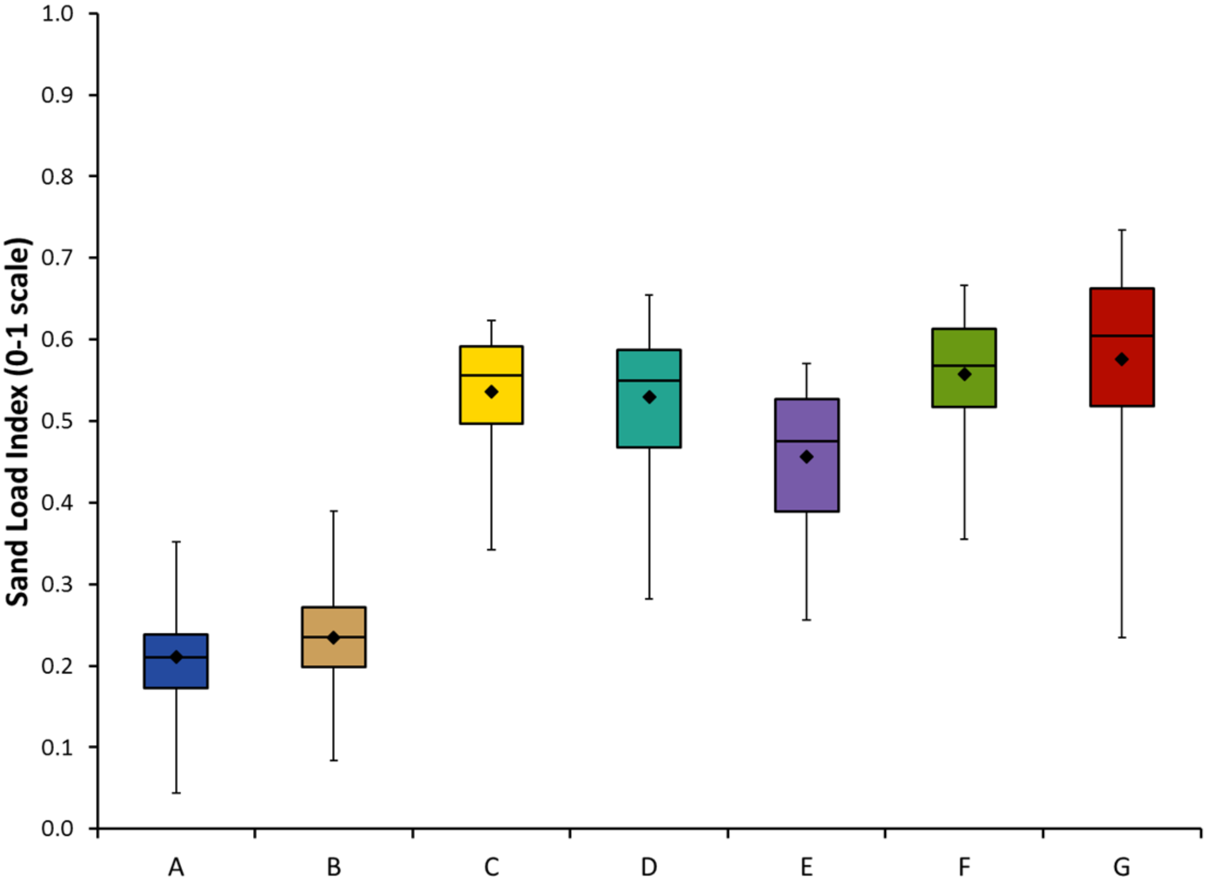

FIGURE 4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven Alternatives (Higher values indicate a greater potential for building sandbars. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

for this alternative are comparable to those under Alternative A. The largest difference is with the timing of the HFEs. The limitation to one HFE every 2 years in Alternative B implies that sandbars should persist throughout the simulation period, although the bars may become smaller during the periods between HFEs.

Under Alternative B, there would be an estimated average net loss of 1,810 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.4 times the annual average Paria River sand input. About 27% of the 63 conditions modeled resulted in a positive sand mass balance. The estimated average net loss of sand under Alternative B is a larger depletion (about 80% higher) compared to Alternative A. This difference can be attributed to the higher within-day fluctuations under Alternative B. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

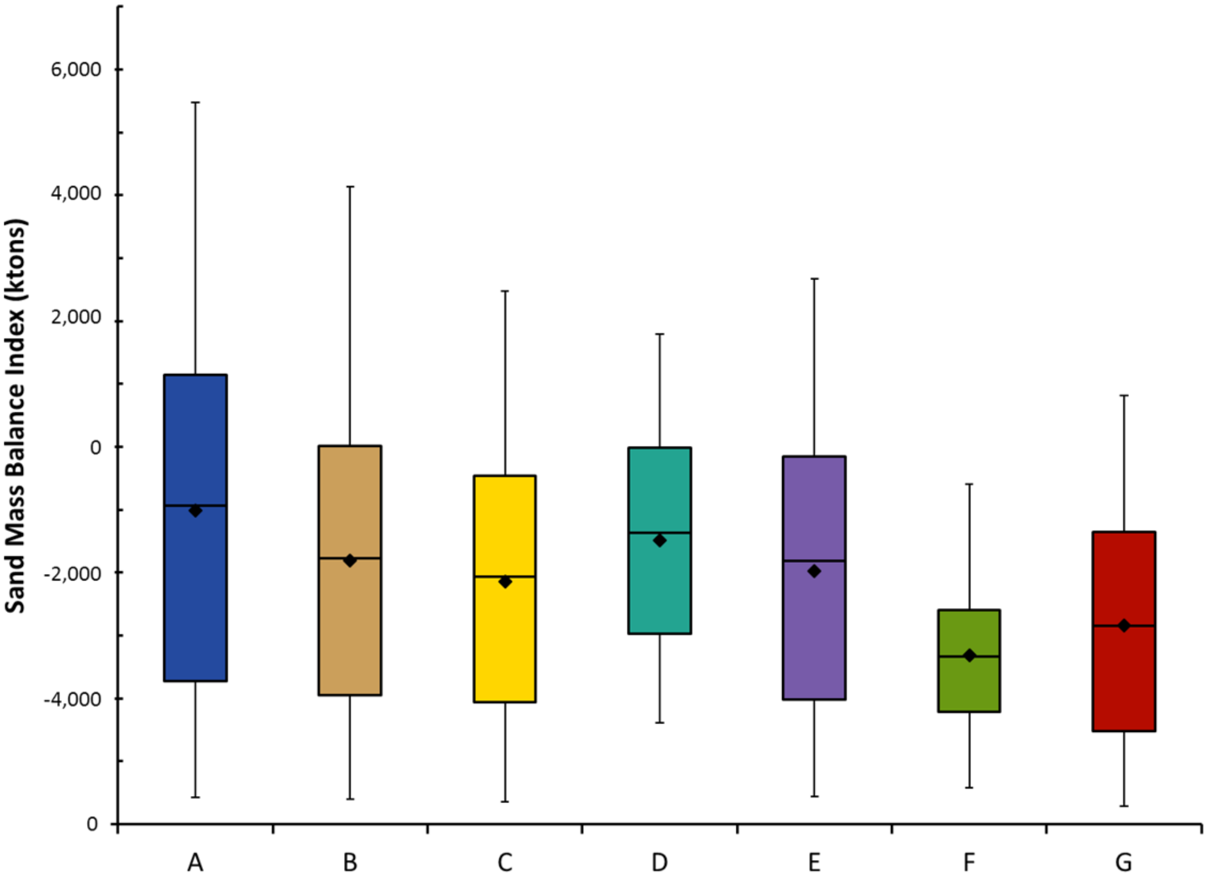

FIGURE 4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the Seven Alternatives (Higher values are considered better than lower values. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative B, including hydropower improvement flows, TMFs, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. Hydropower improvement flows and TMFs were modeled for Alternative B, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

Hydropower improvement flows would feature increased daily fluctuation ranges and ramp rates that would resemble those of operations at Glen Canyon Dam prior to the early 1990s (Section 2.2.2). Under Alternative B, this experimental operation would be implemented a maximum of four times over the 20-year LTEMP period in years with annual volumes of 8.23 maf or less. This additional fluctuation range would reduce the mean sand load index to 0.22, which is still slightly higher than Alternative A, and would result in a sediment depletion of 2,400 kilotons. This larger depletion of sediment is a direct result of the larger daily fluctuation range. This depletion would affect the channel bed sediments and the sandbars, reducing their size.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall there would be minimal adverse impacts on sediment resources because TMFs would not change monthly volumes. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5.1.2). The effect of HFEs on sediment would be much greater than the effects of TMFs on sediment.

In summary, Alternative B has a sandbar-building potential that would be similar to that under Alternative A, but higher fluctuations would result in lower sand mass balance.

4.3.3.3 Alternative C

Under Alternative C, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative C provides for a maximum of 40 sediment-triggered HFEs. On average, there would be 21.3 HFEs triggered and implemented (Figure 4.3-5), which is 53% of the maximum possible under the alternative, and 53% of the overall maximum of 40.

The estimated 20-year weighted average sand load index for Alternative C is 0.54, with an inter-quartile range of 0.50–0.59 (Figure 4.3-6). The estimated average sand load index under Alternative C is 2.6 times greater than the sand load index under Alternative A. This does not imply that bars would be 2.6 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative C. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs as well as proactive spring HFEs. The reduced fluctuations of Alternative C also serve to conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs.

Under Alternative C, there would be an estimated average net loss of 2,140 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.8 times the annual average Paria River sand input. About 22% of the 63 conditions modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP period. The estimated average net loss of sand under Alternative C is a larger depletion (about 112% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on mass balance than operational characteristics of the difference between the alternatives.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative C, including TMFs, proactive spring HFEs, extended-duration HFEs (volume constrained), low summer flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, long-duration HFEs, and low summer flows were modeled for Alternative C, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources (Appendix E). TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5.1.2). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

Proactive spring HFEs are intended to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. Proactive spring HFEs occur in high-volume release years (≥10 maf), unless a sediment-triggered HFE had occurred earlier in the spring. They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit outage at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these proactive HFEs would be effective at building and retaining sandbars, and field tests of this type of HFE are necessary to evaluate their potential effectiveness. Under Alternative C, proactive spring HFEs would only be continued if tests indicate a positive bar response.

Under Alternative C, extended-duration fall HFEs would be of equal release water volume to those triggered under the existing HFE protocol but would be of lower magnitude (e.g., 5-day 36,000 cfs HFE instead of a 4-day 45,000 cfs HFE). The difference in peak and duration for a given release volume will have a relatively minor effect on sediment transport but was not simulated for this analysis. Because of the nonlinear relationship between flow magnitude and sediment transport, a longer duration, same-volume HFE would transport less sand than a shorter duration, higher magnitude HFE. Such an HFE would also have a lower sand load index, and thus would have a lower potential to build sandbars.

Implementation of low summer flows would require higher release volumes in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Due to the nonlinear relationship between sediment transport and flow, this increase in the amount of sand transported during the spring is more than the reduction in transport during low summer flows. The net effect for the year is an increase in overall downstream sand transport, resulting in less sediment being available for sandbar building during an HFE.

In summary, Alternative C would result in higher bar-building potential, but lower sand mass balance than Alternative A.

4.3.3.4 Alternative D (Preferred Alternative)

Under Alternative D, fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input, but spring HFEs would not be allowed in the first 2 years of the LTEMP period. Therefore, Alternative D provides for a maximum of

38 sediment-triggered HFEs. Modeling indicated that on average, there would be 21.1 HFEs triggered and implemented (Figure 4.3-5), which is 55% of the maximum possible under the alternative, and 53% of the overall maximum of 40. Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer).

The estimated 20-year average sand load index for Alternative D is 0.53, with an inter-quartile range of 0.47–0.59 (Figure 4.3-6). The estimated average sand load index under Alternative D is 2.5 times greater than the sand load index under Alternative A. This does not imply that bars would be 2.5 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative D. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, proactive spring HFEs, and extended-duration HFEs during much of the LTEMP period. In addition, the more equal monthly volumes relative to those of Alternative A conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs. Adjustments made to Alternative D after modeling was completed would result in a reduction in the sand load index estimate presented here (see Section 4.1). The prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE, elimination of experimental load-following curtailment after fall HFEs, and adjustments in the monthly release volumes would all contribute to a reduction in sand load index. Alternative D would continue to be ranked fourth among alternatives (between Alternatives C and E) in terms of the sand load index.

Under Alternative D, there would be an estimated average net loss of 1,490 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.0 times the annual average Paria River sand input. About 25% of the 63 conditions modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP period. The estimated average net loss of sand under Alternative D is a larger depletion (about 46% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs and extended-duration HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives. Adjustments made to Alternative D after modeling was completed would result in a reduction in the sand mass balance index estimate presented here (see Section 4.1). The prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE would result in an increase in sand mass balance index, but elimination of experimental load-following curtailment after fall HFEs, and adjustments in the monthly release volumes would contribute to a reduction in sand mass balance index (0.6% and 1.2%, respectively). Alternative D would continue to be ranked second among alternatives (between Alternatives A and B) in terms of sand mass balance index.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative D, including TMFs, proactive spring HFEs, extended-duration HFEs, low summer flows, macroinvertebrate production flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, macroinvertebrate production flows, and low summer flows were modeled as an integral part of Alternative D, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

All HFEs, including proactive spring HFEs, have the largest impact on sediment resources relative to other experimental elements. By definition, proactive spring HFEs are HFEs that occur in 10-maf or greater annual release years when there is limited spring sediment input. They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit outage at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these HFEs would be effective, and field tests of this type of HFE would be needed to evaluate their potential effectiveness. Under Alternative D, proactive spring HFEs would only be continued if tests indicate a positive bar response. As stated above, adjustments made to Alternative D after modeling was complete included prohibition of proactive spring HFEs in the same water year as an extended-duration fall HFE. This prohibition would result in an average of 0.2 fewer proactive spring HFEs over a 20-year period (1.4 compared to 1.6).

Under Alternative D, extended-duration fall HFEs (up to 250 hr) would be implemented during the 20-year LTEMP period, depending on sediment conditions. Modeling demonstrated that extended-duration HFEs would have substantial effects on both the sand load index (increases index value) and the sand mass balance index (decreases index value). Extended-duration HFEs have never been performed in sediment-enriched conditions. The models and existing data suggest that these HFEs could result in substantially greater sandbar building. Extended-duration HFEs would result in higher sand load index values, and consequently higher bar-building potential, than more typical 96-hour or shorter HFEs, but would also transport more sand out of the Marble Canyon reach. Extended-duration HFEs would be tested in up to 4 years during the LTEMP period and only when sufficient sand input from the Paria River would support the extended flow.

Implementation of low summer flows requires higher release volumes in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Due to the nonlinear relationship between sediment transport and flow, this increase in the amount of sand transported during the spring is more than the reduction in transport during low summer flows. The net effect for the year is an increase in overall downstream sand transport, resulting in less sediment being available for sandbar building during an HFE.

Macroinvertebrate production flows would consist of steady flows during the weekends of May through August. These experimental flows are expected to have a relatively minor effect on sand load index and sand mass balance index values.

In summary, Alternative D would result in higher sandbar-building potential than Alternative A, while preserving more sand than all alternatives except Alternative A.

4.3.3.5 Alternative E

Under Alternative E, fall HFEs could be implemented during the 20-year LTEMP period, but spring HFEs would not be implemented in the first 10 years of the program. Therefore, Alternative E provides for a maximum of 30 HFEs during the 20-year period. On average, 17.1 HFEs would be triggered and implemented (Figure 4.3-5), which is 57% of the maximum possible under the alternative, and 43% of the overall maximum of 40.

The estimated 20-year average sand load index for Alternative E is 0.46, with an inter-quartile range of 0.39–0.53 (Figure 4.3-6). The estimated average sand load index is 2.2 times greater than for Alternative A. This does not imply that bars would be 2.2 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative E. Higher bar-building potential is a consequence of the potential for sediment-triggered HFEs throughout the LTEMP period under this alternative. The more equal monthly volumes relative to those of Alternative A also conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs.

Under Alternative E, there would be an estimated average net loss of 1,980 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.6 times the annual average Paria River sand input. The estimated average net loss of sand under Alternative E is a larger depletion (about 96% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative E, including TMFs, low summer flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs and low summer flows were modeled for Alternative E, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5.1.2). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

Implementation of low summer flows would require higher releases of water in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Because sediment transport has a nonlinear relationship with flow, the increase in sand that is transported during the spring is of larger magnitude than the decrease in sediment transport during the summer. The net effect over the year is an increase in overall downstream sand transport, resulting in less sediment being available for transport during an HFE.

In summary, Alternative E would result in higher bar-building potential than Alternatives A and B, but not the other alternatives, and would have lower sand mass balance than Alternative A.

4.3.3.6 Alternative F

Under Alternative F, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative F provides for a maximum of 40 sediment-triggered HFEs. Under the alternative, in years when a spring HFE was not triggered, there would be a 24-hour 45,000 cfs release in the beginning of May, regardless of the availability of sediment. On average, 19.3 sediment-triggered HFEs would be called for in the 20-year LTEMP period (Figure 4.3-5), which is 48% of the maximum possible under the alternative, and 48% of the overall maximum of 40 (one spring and one fall HFE every year). If the alternative-prescribed annual May events in years without sediment-triggered HFEs are counted, there are on average 38.1 HFEs during the 20-year LTEMP period.

The estimated 20-year average sand load index for Alternative F is 0.56, with an inter-quartile range of 0.52–0.61 (Figure 4.3-6). The estimated average sand load index under Alternative F is 2.7 times greater than the sand load index under Alternative A. This does not imply that bars would be 2.7 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative F. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, as well as a 24-hour 45,000 cfs release in May in years when a spring HFE is not triggered by sediment input.

Under Alternative F, there would be an estimated average net loss of 3,320 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 4.4 times the annual average Paria River sand input, about 230% higher than under Alternative A. This is the largest depletion associated with any of the alternatives, resulting from the high frequency of HFEs, including an alternative-prescribed flood every spring regardless of tributary sediment inflows, as well as extended elevated flow releases (approximately 20,000 cfs) for the duration of May and June. None of the 63 conditions modeled resulted in a positive mass balance at the end of the LTEMP period. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that that future hydrology and sediment input results in a lesser impact on the mass balance than the alternative.

Other than sediment-triggered spring and fall HFEs, no experimental elements are identified under this alternative.

In summary, Alternative F has the highest number of HFEs and would result in the highest bar-building potential, but the lowest sand mass balance of all alternatives.

4.3.3.7 Alternative G

Under Alternative G, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative G provides for a maximum of 40 sediment-triggered HFEs. On average, 24.5 HFEs would be triggered and implemented (Figure 4.3-5), which is 61% of the maximum possible under the alternative, and 61% of the overall maximum of 40. This is the only alternative that would allow for HFE durations of up to 336 hr at the 45,000-cfs peak flow rate, and there would be no limit to the number of extended-duration HFEs as long as they could be supported by sediment inputs.

The estimated 20-year average sand load index for Alternative G is 0.58, with an inter-quartile range of 0.52–0.66. This is the alternative with the highest average sand load index. The estimated average sand load index for Alternative G is 2.8 times greater than the sand load index for Alternative A. This does not imply that bars will be 2.8 times larger under this alternative as compared to Alternative A, but it does suggest that there would be significantly more bar-building potential under Alternative G. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, proactive spring HFEs, and extended-duration HFEs during the entire LTEMP period. The lack of daily fluctuations under Alternative G and equal monthly volumes also would conserve more sediment during normal operations, thus making more sediment available for transport during HFEs.

Under Alternative G, there would be an estimated average net loss of 2,840 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 3.7 times the annual average Paria River sand input. About 6% of the 63 conditions modeled resulted in a positive mass balance at the end of the LTEMP period. The estimated average net loss of sand under Alternative G represents a depletion that is about 182% greater than that under Alternative A. This difference can be attributed to the higher number of HFEs and extended-duration HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in as much impact on the mass balance as the alternative definition.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative G, including TMFs, proactive spring HFEs, extended-duration HFEs, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, and extended-duration HFEs were modeled for Alternative G, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would have a minimal effect on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

All HFEs, including proactive spring HFEs, have the largest impact on sediment resources relative to other experimental elements. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these HFEs would be effective, and field tests of this type of HFE would be needed to evaluate their potential effectiveness. Under Alternative G, proactive spring HFEs would only be continued if tests indicate a positive bar response.

In this alternative, extended-duration HFEs may be up to 336 hr long and would be triggered by the appropriate sediment conditions. Modeling demonstrated that extended-duration HFEs would have important effects on both the sand load index (increases index value) and the sand mass balance index (decreases index value). Extended-duration HFEs have never been performed in sediment-enriched conditions. The models and existing data suggest that these HFEs could result in substantially greater sandbar building.

In summary, Alternative G has the second-highest number of HFEs and would result in the second-highest bar-building potential and the second-lowest sand mass balance of all alternatives.

4.4 NATURAL PROCESSES

Issue: How do alternatives affect physical conditions which drive the natural processes that support native plants and animals, and their habitats, in Glen and Grand Canyons?

Impact Indicators:

- Flow characteristics, including monthly release patterns and within-day variability
- Seasonal water temperature patterns
- Sediment mass balance and sandbar building potential
- Water quality (nutrients and turbidity)

The Colorado River Ecosystem is defined as the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (GCNP). It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. An important objective of management of the Colorado River Ecosystem is the ability to sustain healthy populations of native plants and animals. As described in Chapter 3, management policies identified by the NPS (NPS 2006d) state that “whenever possible, natural processes will be relied upon to maintain native plants and animals and influence natural fluctuations in populations of these species.”

Major physical drivers of natural processes in the Colorado River Ecosystem are flow, water temperature, sediment transport, and water quality (including nutrients and turbidity). The nature of these parameters directly and/or indirectly determines the abundance, condition, and status of habitats for native and nonnative plants and animals in the ecosystem below the dam.

The natural processes within the Colorado River Ecosystem reflect historic changes to the system (Chapter 3). The existing facilities and laws and regulations further constrain the options for fully restoring the original natural processes within the canyon. It is not possible to operate the dam in a manner that could restore to pre-dam conditions the physical parameters that drive natural processes. Nonetheless, physical and chemical parameters that influence natural processes and native and nonnative species communities may be affected differently by each of the LTEMP alternatives.

4.4.1 Analysis Methods

The range of variability of physical parameters in the Colorado River Ecosystem is constrained by the operational limits of the dam, but varies by alternative. It is assumed that the natural abundance, diversity, and genetic and ecological integrity of plant and animal species native to the river will be influenced by the physical riverine conditions that are produced under each alternative.

A conceptual model showing expected linkages among dam releases, physical conditions, habitats, and affected ecological resources is shown in Figure 4.4-1. As shown, the primary effects of any alternative on plant and animal species below the dam will be a direct function of the changes in the physical conditions (e.g., sediment transport, water temperature) that would occur under each alternative; how those alternative-specific changes affect habitat quality, quantity, and stability; and how aquatic and terrestrial biota will respond to those changes. Thus, the evaluation of how each alternative may affect natural processes below Glen Canyon Dam was based on the examination of how selected physical parameters would differ under each alternative. These differences in physical parameters were assessed as described in Sections 4.2.1 (for temperature-, flow-, and water-quality-related indicators) and 4.3.1 (for sediment-related indicators). These evaluations were then considered together to provide a qualitative determination of how natural processes in the river below Glen Canyon Dam would be affected under each alternative. Table 4.4-1 identifies the role of each of the physical parameters in influencing natural processes in the Colorado River Ecosystem.

4.4.2 Summary of Impacts

One of the most important factors affecting ecological resources (i.e., native plants and animals and their habitats) in the Colorado River Ecosystem is the interannual variability in the hydrology of the system, as driven by weather patterns and climatic conditions. Under a natural hydrograph, physical conditions in the river would include a hydrograph with peak flows and volumes in later spring/early summer, daily flows ranging on average from 1,000 cfs in winter to >92,000 cfs in spring and summer, and daily fluctuations only in response to precipitation events and tributary inflows (Section 3.2.2.2). Water temperatures would range from near freezing in winter to 30°C (86°F) in the late summer, and turbidity would be high throughout the year

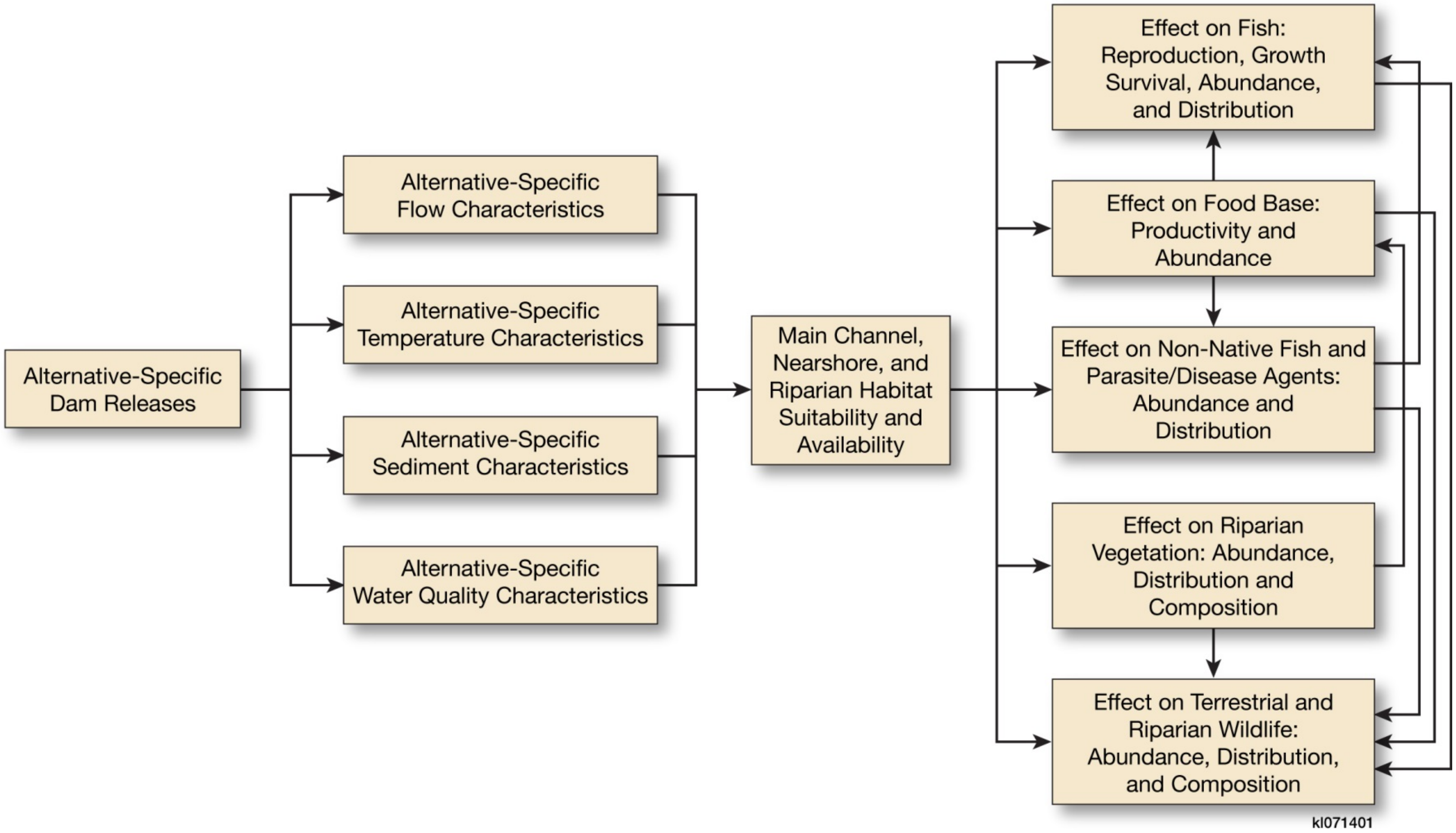

FIGURE 4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats, and Ecological Resources in the Colorado River Ecosystem

TABLE 4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative

Indicator	Role in Affecting Natural Processes
Flow-Related Indicators	
Peak and base flows	The frequency, magnitude, duration, and timing of peak and base flows directly affect aquatic and riparian habitats and their biota, as well as other physical factors such as water temperature and sediment transport, deposition, and loss, which in turn affect aquatic and riparian habitats, native fish and aquatic invertebrates, the aquatic food base, and riparian vegetation and wildlife. There are also direct effects from peak and base flows on vegetation.
Monthly release volumes	The magnitude and pattern of monthly release volumes affect sediment transport and physical conditions that influence important life history parameters of aquatic biota, such as egg laying and hatching in fish, as well as the quality and quantity of mainstem and nearshore aquatic habitats and riparian habitats along the main channel.
Mean daily flows	The magnitude and pattern of daily flows (including ramp rates) affect main channel and nearshore aquatic habitats, riparian habitats, and the biota that rely on these habitats.
Mean daily flow fluctuations	Daily flow fluctuations (including ramp rates) affect sediment transport and directly affect daily changes in stage, which in turn affect mainstem riparian vegetation, main channel and nearshore aquatic habitat stability, and productivity and distribution of the aquatic food base.
Temperature-Related Indicators	
Mean main channel water temperatures	Water temperatures affect reproduction, growth, and survival of fish and aquatic invertebrates in main channel and nearshore habitats, as well as productivity of the aquatic food base.
Sediment-Related Indicators	
Sediment transport and deposition	These sediment parameters affect main channel and nearshore aquatic habitats as well as riparian habitats, the biota that rely on these habitats, and the aquatic food base.
Elevation of annual sediment deposition	Elevation of annual sediment deposits affects distribution, abundance, and composition of riparian vegetation and terrestrial wildlife habitat.
Water-Quality-Related Indicators	
Turbidity	Turbidity affects predator-prey relationships among aquatic biota, as well as primary productivity.
Nutrients	Nutrients affect aquatic habitat quality for fish, invertebrates, and the aquatic food base.

(Section 3.2.3.2). It is under such conditions that natural processes would act to develop, support, and maintain the original native ecosystems of the river.

The nature, magnitude, pattern, and duration of flows, as well as water temperatures and water quality, in the Colorado River Ecosystem are so strongly constrained by the presence of the dam and by the existing laws and regulations that govern conveyance of water between the Upper and Lower Basins that it is not possible for any of the alternatives to restore natural processes in the system to pre-dam conditions. In addition to their effects on flow, Glen Canyon Dam and Lake Powell trap most of the sediment from the Upper Basin that would normally be transported into and through the Colorado River in Glen and Grand Canyons. The dam also serves as a physical barrier to the movement of riverine organisms between the Upper and Lower Basins. In this context, the LTEMP alternatives have relatively similar effects and have the potential to produce only relatively small changes in current conditions that could improve natural processes.

Regardless of which alternative is implemented, there would be little change from current conditions with regard to maximum daily flow limit (25,000 cfs), minimum daily flow limit (5,000 to 8,000 cfs), mean Glen Canyon Dam release water temperature, overall turbidity or nutrient concentrations, or the maximum height of annual sediment deposition (elevation of 45,000 cfs flows). Thus, natural processes dependent on these physical factors would not differ from current operations, and these are not discussed further in the analysis below.

Some changes in natural processes may be expected under all alternatives, as reflected by expected changes in one or more of the physical indicators, but these changes from current conditions are expected to be relatively modest, especially for the fluctuating flow alternatives (Alternatives B–E) (Table 4.4-2). By altering the monthly release patterns and eliminating within-day fluctuations, the two steady-flow Alternatives F and G would result in the greatest changes to natural processes relative to those under current conditions.

Alternatives with greater daily flow fluctuations (Alternatives B and E) could result in reductions in nearshore habitat stability compared to the other alternatives, and thus have greater impacts on aquatic and riparian biota in nearshore habitats (Sections 4.5, 4.6, and 4.7).

Compared to Alternative A, natural processes influenced by sediment dynamics would be improved under other alternatives because the potential for sandbar building (as inferred from sand load index estimates) would increase. In contrast, sediment depletion from Marble Canyon (as inferred from sand mass balance index estimates) would increase for these alternatives compared to Alternative A. This sediment depletion, however, would be balanced by greater deposition of sediment in areas above the normal range of flows where that sediment could benefit terrestrial ecosystems. This redistribution of sediment would restore, albeit to a limited extent, the natural pattern of sediment distribution.

Alternative F may have the greatest effect of all alternatives on natural processes. Alternative F is the only alternative with a monthly release pattern that has been seasonally adjusted to more closely follow the seasonal pattern of inflow and (along with Alternative G) has the least daily flow fluctuations, which would result in more stable and presumably higher

TABLE 4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated with Flow, Water Temperature, Water Quality, and Sediment Resources[a]

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Existing natural processes related to flow, water temperature, water quality, and sediment resources would continue, but replenishment of sandbars would diminish after 2020, when HFEs would cease.	Compared to Alternative A, most natural processes would be unchanged, but there would be less nearshore habitat stability as a result of greater within-day fluctuations.	Compared to Alternative A, there would be more nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer and fall water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be comparable nearshore habitat stability as a result of similar within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be lower nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within season variability; more frequent sandbar building resulting from more frequent HFEs..	Compared to Alternative A, year-round steady flows would result in the greatest nearshore habitat stability, slightly higher summer water temperatures, and the highest potential of any alternative to build sandbars and retain sand in the system.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Flow-Related Indicators							
Peak and base flows	No change from the current frequency, magnitude, and timing of HFE releases and base flows; spring and fall HFEs would occur when triggered until existing protocol expires in 2020.	Spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period; number of HFEs would be limited to no more than one every other year..	Spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs and proactive spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff..	Fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs and proactive spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff, but would not be implemented in first 2 years.	Fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff, but would not be implemented in first 10 years.	An annual hydrograph that features a 2-month long peak flow period and relatively low summer, fall, and winter base flows would support natural processes dependent on natural patterns of snowmelt runoff; spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period.	Spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs and proactive spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff..
Mean monthly release volume and mean daily flow	No change from current conditions, with highest mean monthly release volumes and mean daily flows in winter and summer.	Same as Alternative A.	Higher mean monthly volumes and mean daily flows in winter, spring, and summer with lowest volumes in late summer and autumn favoring conservation of sediment inputs during the monsoon period.	Relatively even monthly volumes and mean daily flows favoring conservation of sediment year-round.	Relatively even monthly volumes and mean daily flows, but lower volumes in late summer favoring conservation of sediment inputs during the monsoon period.	Monthly volumes and daily flows seasonally adjusted to more closely match monthly pattern of inflows with high spring flows and low summer through winter flows.	Monthly volumes and daily flows are approximately equal, favoring conservation of sediment year-round.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Flow-Related Indicators (Cont.)							
Mean daily changes in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs; no change from the current daily maximum limit of of 25,000 cfs, and daily minimum limit of 5,000 to 8,000 cfs.	Mean daily change higher in all months (range about 2,500 to 12,000 cfs, and even higher with hydropower improvement flows), which could reduce stability of nearshore habitats; no change from the current daily maximum and minimum limits.	Mean daily change lower in all months (about 1,300 to 6,200 cfs), which could increase stability of nearshore habitats; no change from the current daily maximum and minimum limits.	Mean daily change slightly higher in Oct. through Jun., which could slightly reduce nearshore habitat stability. Mean daily change in other months comparable to Alternative A (range about 2,700 to 7,600 cfs); no change from the current daily maximum and minimum limits.	Mean daily change higher in all months but Sept. and Oct. (range about 1,100 to 9,600 cfs), which could reduce stability of nearshore habitats; no change from the current daily maximum and minimum lmits.	Steady flows will increase stability of nearshore habitats; no change from the current daily maximum and minimum limits.	Steady flows will increase stability of nearshore habitats; no change from the current daily maximum and minimum limits.
Temperature-Related Indicators							
Mean Glen Canyon Dam release water temperature	Mean seasonal release temperatures are expected to be about 9.9°C in winter (about 9.7–10.2°C), 9.0°C in spring (8.8–9.2°C), 11.3°C (10.9–11.4°C) in summer, and 12.2°C (11.9–12.4°C) in fall.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Temperature-Related Indicators (Cont.)							
Mean seasonal main channel water temperature and downstream warming	No change from current conditions. Mean seasonal water temperatures between Lees Ferry and Diamond Creek range 10.0–10.6°C in winter, 9.3–13.5°C in spring, 11.6–17.2°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.6°C.	Same as Alternative A.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.2°C in spring, 11.7–17.6°C in summer, and 12.3–15.9°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.5°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.3°C in spring, 11.6–17.6°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 6.0°C.	Mean seasonal water temperatures range 9.9–10.6°C in winter, 9.5–12.5°C in spring, 11.9–18.6°C in summer, and 12.3–16.0°C in fall. Greatest amount of winter (0.9°C), summer (6.7°C), and fall (3.7°C) warming, and least amount of spring (3.0°C) warming of all alternatives.	Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.8°C in summer, and 12.4–15.3°C in fall. Second highest summer warming (6.2°C) of all alternatives.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Sediment-Related Indicators							
Sediment transport and deposition	No change from current conditions with reduction of sandbar area and volume after HFE protocol expires in 2020; 20-yr average SLI of 0.21 and SMBI of −1,010.	Slight increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates; an 11% increase in the SLI, which could slightly increase sandbar building potential, and an 80% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; lower fluctuations would result in lower erosion and transport rates; a 154% increase in the SLI and a 112% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; fluctuations comparable to Alternative A; a 151% increase in the SLI and a 47% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates; a 116% increase in the SLI and a 96% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates; a 164% increase in the SLI and a 230% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates; a 173% increase in the SLI and a 182% decrease in the SMBI compared to Alternative A.
Water Quality-Related Indicators							
Turbidity	No change from current conditions expected.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.
Nutrients	No change from current conditions expected.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.

[a] SLI = sand load index; SMBI = sand mass balance index.

quality nearshore and riparian habitats (Sections 4.5, 4.6, and 4.7). Under Alternative F, the timing of achieving suitable downstream main channel water temperatures could reduce overall temperature suitability for spawning and incubating humpback chub and other native fishes, but improve temperatures for growth of young-of-year (YOY) humpback chub (Section 4.5.2.1).

4.4.3 Alternative-Specific Impacts

Although alternatives did not differ with regard to minimum and maximum daily flow limits, mean Glen Canyon Dam release water temperature, turbidity, or nutrient concentrations, alternatives do differ with regard to the frequency, magnitude, and timing of HFEs, monthly flow volumes, mean daily flows, within-day flow fluctuations, and sediment dynamics (Table 4.4-2). These factors have the potential to produce only small changes in current conditions and thus are expected to have relatively small effects on natural processes, as discussed below. In 2026, the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a) that are currently in place will expire. Without knowing how dam operations may change at that time, it is not possible to postulate with any acceptable level of certainty how natural processes may be affected. Thus, the following assessments of alternative-specific impacts do not consider any changes in operations after 2026.

4.4.3.1 Alternative A (No Action Alternative)

Under Alternative A, there would be little change in physical parameters from current conditions; mean monthly release volumes, mean daily flows, and mean daily changes in flow would be the same as current conditions (Section 4.2). Because the current HFE protocol as defined in the 2011 EA (Reclamation 2011b) would continue under Alternative A, sediment deposition rates would not be expected to differ from current levels. Sandbar building would be expected to continue through the HFE protocol window, but bars would likely then erode and decrease in size after 2020 (Section 4.3). Vegetation and wildlife dependent on replenished sandbars would decline in abundance after the protocol expires in 2020 (Sections 4.6 and 4.7).

In summary, under Alternative A, no changes from current conditions are expected in physical factors associated with monthly volumes, daily flows, and flow changes, water temperature, and water quality. As a consequence, natural processes in the Colorado River Ecosystem are not expected to differ from current conditions (Table 4.4-2).

4.4.3.2 Alternative B

Under Alternative B, mean monthly volumes and mean daily flows would be the same as those under Alternative A (Sections 4.2 and 4.3), and thus natural processes influenced by these parameters are not expected to change from current conditions. However, Alternative B would have a greater mean daily change in flow in all months (Section 4.2), and thus may affect natural processes that support aquatic ecology and vegetation, decreasing nearshore habitat stability and affecting native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that inhabit these areas (Section 4.5). Under Alternative B, no changes from current conditions are expected in physical factors associated with monthly volumes, daily flows, and water temperature.

Sediment-triggered spring HFEs under Alternative B would support natural processes that are dependent on natural patterns of snowmelt runoff, but would be limited in frequency compared to all alternatives except for Alternative A. While the average and maximum number of sediment-triggered HFEs would be similar to that under Alternative A, the sand load index (an indicator of sandbar building potential) could be higher under Alternative B (Section 4.3). Thus, sediment-influenced natural processes that affect riparian vegetation, terrestrial wildlife, and nearshore aquatic habitats could be somewhat improved under Alternative B, but would be lower relative to other alternatives, which have more frequent HFEs. Within-day flow fluctuations would result in higher rates of sandbar erosion than under any other alternative.

In summary, in comparison to Alternative A, the higher mean daily changes in flow under Alternative B in all months may act to decrease sediment conservation and favor wetland processes (unless hydropower improvements are implemented), but reduce nearshore habitat stability, which would affect fish, aquatic invertebrates, benthic productivity, and riparian species in those habitats (Table 4.4-2).

4.4.3.3 Alternative C

Mean monthly volumes as well as mean daily flows under Alternative C would be higher in February through May, but lower in August through October when compared to Alternative A. In addition, within-day changes in flow would be lower in all months under Alternative C than under Alternatives A, B, D, and E. The lower magnitude of daily fluctuations under Alternative C would improve the quality and stability of some nearshore habitats and benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species (Sections 4.5, 4.6, and 4.7).

Sediment-triggered and proactive spring HFEs under Alternative C would support natural processes dependent on natural patterns of snowmelt runoff. The relatively high frequency of spring HFEs relative to Alternatives A, B, and E would also contribute to those processes. Reduced volume in August through November would favor sediment retention during the monsoon period and increase the frequency, magnitude, and duration of fall HFEs, the size and persistence of sandbars, and the aquatic and riparian species that depend on these habitats (Sections 4.3, 4.6, and 4.7). These lower monthly volumes would also favor some increased warming in the summer and fall compared to Alternative A. The lower magnitude of daily changes in flows under Alternative C would reduce the erosion rates of sandbars.

In summary, compared to Alternative A, the higher monthly release volumes and daily flows in winter, spring, and summer, as well as the lower mean daily changes in all months under Alternative C, may increase sediment conservation and increase the stability of nearshore habitats and thus benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that use those habitats (Table 4.4-2). The relatively high frequency of spring

HFEs would support natural processes dependent on natural patterns of snowmelt runoff. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.4.3.4 Alternative D (Preferred Alternative)[8]

Compared to Alternative A, Alternative D would have slightly higher mean monthly volumes and daily flows in November and February through April, and lower volumes and flows in December, January, and July, August, and September (Section 4.2), providing less seasonal variation in flow across the year than most alternatives. Mean daily changes in flow for Alternative D would be comparable to Alternative A. Thus natural processes influenced by daily changes in flow would differ little from current conditions, and the quality and stability of some nearshore aquatic habitats (including backwaters) would be comparable to those under current conditions. Under Alternative D, there would be some increased warming, especially in summer, compared to Alternative A.

Sediment-triggered and proactive spring HFEs under Alternative D would support natural processes dependent on natural patterns of snowmelt runoff. The relatively high frequency of spring HFEs relative to Alternatives A, B, and E would also contribute to those processes. The relatively even pattern of monthly volumes would serve to conserve sand, and, as a consequence, spring and fall HFEs would be triggered frequently under Alternative D. Thus, this alternative has a relatively high potential for sandbar building compared to other alternatives (Section 4.3). The higher number of HFEs could increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats (Sections 4.6 and 4.7).

In summary, natural processes influenced by monthly volumes, daily flows, and within-day changes in flow would differ little between Alternatives A and D (Table 4.4-2). However, the more even monthly release volumes and daily flows would favor sediment conservation and also provide some increase in downstream water temperatures especially in the summer. The relatively high frequency of spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.4.3.5 Alternative E

Compared to Alternative A, mean monthly volumes as well as mean daily flows under Alternative E would be higher in October, November, February, and March, but lower in December, January, July, August, and September. This increase in within-day fluctuations may affect natural processes that support aquatic ecology and vegetation, decreasing nearshore habitat stability and affecting native fish, trout, benthic productivity, aquatic invertebrates, and riparian

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[8] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on natural processes.

species that inhabit these areas (Sections 4.5, 4.6, and 4.7). Lower August release volumes would favor some increased warming in the summer compared to Alternative A.

Sediment-triggered spring HFEs under Alternative E would support natural processes dependent on natural patterns of snowmelt runoff, but their lower frequency would not provide the same level of benefit as Alternatives C, D, F, and G. August and September volumes would be lower to conserve sediment during the monsoon period. The mean daily change in flow under Alternative E would be higher than under Alternative A in all months but September and October, when the daily change would be lower. The greater daily change in flow under this alternative could increase the erosion rates of sandbars. This alternative has a relatively high potential for sandbar building, compared to other alternatives (Section 4.3). The higher number of HFEs could increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats.

In summary, in comparison to Alternative A, the relatively even monthly release volumes and daily flows of Alternative E, together with lower summer volumes and flows, would favor sediment conservation during monsoon periods, and would provide some increase in downstream water temperatures, especially in the summer. Higher mean daily changes in flow in all months but October and November may reduce nearshore habitat stability, which would affect fish, aquatic invertebrates, benthic productivity, and riparian species in those habitats (Table 4.4-2). Sediment-triggered spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff, but their frequency would be low relative to Alternatives C, D, F, and G. The high frequency of sediment-triggered HFEs would increase sandbar building relative to Alternative A.

4.4.3.6 Alternative F

In contrast to all other alternatives, Alternative F has a pattern of monthly volumes and daily flows that are seasonally adjusted to more closely match the pattern of Lake Powell inflow and the natural snowmelt runoff pattern, with high spring flows and low summer through winter flows. Under Alternative F, the highest mean monthly release volumes and mean daily flows occur in March through June, and lower volumes and daily flows occur in December, January, and July through August (Section 4.2). Under Alternative F, there would be no within-day flow changes except those needed for HFEs or other high-flow releases, or as a result of changes in the runoff forecast, equalization flows, or natural precipitation events and tributary inflows. This alternative has the highest number of HFEs of all the alternatives. Thus among all the alternatives, Alternative F is expected to result in flow-related natural processes that are most different from current conditions, but most similar to an unregulated condition. Steady flows are expected to reduce the erosion of sandbars, provide for more stable main channel and nearshore aquatic habitats, and increase productivity in these habitats (Sections 4.5, 4.6, and 4.7).

Relative to other alternatives, Alternative F would have the lowest water temperatures in spring and the warmest temperatures in summer (Section 4.2). This pattern and magnitude of downstream warming are due, in part, to the monthly patterns in release volumes and daily flows, as well as the relative absence of daily flow fluctuations, under Alternative F. As a result, temperature-linked natural processes could be affected more under Alternative F than under any of the other alternatives..

Alternative F has a greater potential for sediment conservation and deposition, and significantly more potential for sandbar building, than any other alternative but Alternative G. These HFEs would increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats.

In summary, the monthly release volumes and daily flows under Alternative F would more closely match the pattern of inflows, with high spring and low summer through winter flows. In comparison with Alternative A, this pattern of monthly volumes and daily flows, together with steady within-day flows, would increase sediment conservation and increase the stability of nearshore habitat stability, and thus benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that use those habitats (Table 4.4-2). Alternative F would have the least amount of spring warming, and the greatest amount of summer warming of all alternatives. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.4.3.7 Alternative G

Under Alternative G, mean monthly volumes as well as mean daily flows would be higher in October, November, and February through April, but lower in December, January, July, and August (Section 4.2). These steady flows would serve to conserve sediment relative to other alternatives, but would provide no seasonal variability, and therefore could affect natural processes reliant on such variability. There would be no mean daily changes in flow except for ramping during HFEs or in response to changes in the runoff forecast, equalization flows, or precipitation events and tributary inflows. Steady flows are expected to reduce the erosion of sandbars, improve the quality and stability of nearshore and main channel aquatic habitats, and increase benthic productivity (Section 4.5).

Alternative G would have less downstream warming, and thus cooler downstream main channel water temperatures in spring and warmer downstream temperatures in summer, compared to Alternative A and all other alternatives but Alternative F (Section 4.2). As with Alternative F, this pattern of downstream warming is due, in part, to the pattern of monthly release volumes under Alternative G.

Sediment-triggered and proactive spring HFEs under Alternative G would support natural processes that are dependent on natural patterns of snowmelt runoff. The relatively high frequency of spring HFEs relative to Alternatives A, B, and E would also contribute to those processes. Alternative G has the highest average number of sediment-triggered HFEs of all the alternatives (Section 4.3). These HFEs would result in the most bar-building of any of the alternatives, increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats (Sections 4.6 and 4.7).

In summary, the more even monthly release volumes and daily flows under Alternative G, together with steady within-day flows, may increase sediment conservation and increase nearshore habitat stability, and thus benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that use those habitats (Table 4.4-2). This alternative also has the second-highest summer warming of all alternatives. The relatively high frequency of spring HFEs would support natural processes that are dependent on natural patterns of snowmelt runoff. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.5 AQUATIC ECOLOGY

The assessment of impacts on aquatic ecology focused on four groups of aquatic resources: the food base (consisting of invertebrates, algae, and aquatic plants), native fish (including the endangered humpback chub [*Gila cypha*]), nonnative fish (including rainbow trout [*Oncorhynchus mykiss*]), and aquatic fish parasites. The specific attributes and conditions evaluated, the analysis methods, and the assessment results are presented in the following sections. Additional details are provided in Appendix F.

Issue: How do alternatives affect aquatic resources (food base, native and nonnative fishes, and fish parasites) between Glen Canyon Dam and Lake Mead?

Impact Indicators:

- Abundance, distribution, and availability of the aquatic food base
- Native and nonnative fish reproduction, survival, growth, and distribution
- Availability and quality of aquatic habitats
- Distribution and potential for spread of fish parasites

4.5.1 Analysis Methods

The evaluation of the potential impacts of LTEMP alternatives on aquatic resources below Glen Canyon Dam is based on alternative-specific differences in operations (including monthly and annual flow patterns and within-day flow fluctuations), and flow and non-flow actions. These characteristics of alternatives can affect aquatic organisms directly or through their effects on habitat availability and quality. The analysis methods for impacts on aquatic food base, native fish, nonnative fish, and aquatic parasites are presented next.

4.5.1.1 Aquatic Food Base

The aquatic food base assessment considers the effects of flow and temperature on the amount of food that is available to fish and other animals in Glen and Grand Canyon. The assessment focuses on changes at key locations in the Colorado River: RM 0 (Lees Ferry within the Glen Canyon reach), RM 61 (Little Colorado River within the Marble Canyon reach), and RM 225 (Diamond Creek within the Grand Canyon reach). As discussed in Section 3.2.1.2, within-day flow variation in releases continues downstream and decreases little as flows pass through Marble and Grand Canyons. Water, on the other hand, can warm considerably by the time it travels from the dam to western Grand Canyon (Section 3.2.2.2).

The effects of flow and temperature on the aquatic food base were evaluated by examining a number of important factors. The potential influence of flow on the aquatic food base includes changes in invertebrate drift (food organisms dislodged and moved by river current, e.g., algae, plankton, invertebrates, and larval fish); stranding of aquatic organisms in the varial zone (the portion of the river's edge affected by the daily range of flows); and effects to species abundance, composition, and diversity. Stranding of organisms in the varial zone may lead to their death, while growth of primary producers such as *Cladophora* is reduced in the varial zone. The potential influence of temperature includes changes in diatom composition; invertebrate egg development, fecundity, growth, maturation, number of yearly generations, and/or emergence of adults for aquatic insects with terrestrial adult stages; invertebrate composition, diversity, and production (e.g., biomass of benthic macroinvertebrates per unit of area per unit of time); and occurrence and distribution of invasive and parasitic species (Clarke et al. 2008; Poff et al. 1997; Power et al. 1988; Renöfält et al. 2010).

To assess potential flow effects on the aquatic food base, a qualitative comparison among alternatives was conducted because an appropriate quantitative model was not available. This qualitative analysis was based on potential impacts of elements of base operations (e.g., release volumes, maximum and minimum flows, daily flow range, and ramp rates) and other experimental flow actions (e.g., HFEs, low summer flows, TMFs, and hydropower improvement flows). To assess potential temperature effects on the aquatic food base, expected mean monthly temperatures at Lees Ferry, Little Colorado River, and Diamond Creek were compared to temperature requirements for select primary producers, zooplankton, and benthic macroinvertebrate species (Valdez and Speas 2007).

4.5.1.2 Nonnative Fish

The assessment of impacts on nonnative fish evaluated effects on reproduction, survival, growth, and abundance downstream of Glen Canyon Dam. The assessment considered results of previous investigations conducted below Glen Canyon Dam that examined the status and abundance of nonnative fish (e.g., see Makinster et al. 2010), as well as studies of the effects of experimental flows (such as HFEs and trout removal flows) on nonnative fish (e.g., Makinster et al. 2011; Korman et al. 2012; VanderKooi 2015; Gimbel 2015). In addition, species-specific models that incorporated factors such as annual release volumes, water temperatures, and monthly and within-day changes in flows were used to examine effects at selected locations downstream of Glen Canyon Dam.

A coupled rainbow trout–humpback chub model was used to evaluate potential effects of alternatives on (1) the number and size of rainbow trout in the Glen Canyon reach, and (2) the number of age-0 rainbow trout expected to move (emigrate) into the Marble Canyon and Little Colorado River reaches over the 20-year LTEMP period. The model estimates the number of rainbow trout that move downstream as a function of trout spawning and recruitment in the Glen Canyon reach. Historic observations and previous modeling suggest that recruitment of rainbow trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in years with HFEs (especially spring HFEs), and in years with lower levels of within-day fluctuations (Korman, Kaplinski et al. 2011; Korman, Persons et al. 2011; Korman et al. 2012;

Section 3.5.4). Recruitment for a given year was predicted to be higher if a spring HFE occurred in that year or in the previous year, based upon empirical relationships reported by Korman et al. (2011c). At the time modeling was conducted, there was insufficient information to draw a conclusion about whether fall HFEs would have a similar effect on the recruitment of trout. The model considered this uncertainty about the effect of fall HFEs on trout recruitment by examining two hypotheses: (1) fall HFEs would have no effect on recruitment and (2) recruitment would increase at the same rate as seen with spring HFEs, but for only 1 year instead of 2 years. Preliminary analyses of recent studies indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015).

The number of trout recruits in the Glen Canyon reach, and the numbers of trout and humpback chub in the Little Colorado River reach were used to determine when TMFs and mechanical removal in the Little Colorado River reach, respectively, would be triggered under certain alternatives. As described in Appendix F, TMFs are triggered in the rainbow trout–humpback chub model when the estimated number of YOY trout in the Glen Canyon equal or exceed 200,000. The actual trigger implemented could be higher or lower depending on the results of experiments, and these triggers would be developed in consultation with the Arizona Game and Fish Department (AZGFD) and other entities as appropriate (Section 2.2.4.6).

Two factors must coincide to trigger mechanical removal trips in the rainbow trout–humpback chub model: (1) there must be more than 760 adult rainbow trout projected for the test reach in the vicinity of the Little Colorado River confluence (RM 63–RM 64.5) and (2) the projected adult humpback chub population must be less than 7,000 individuals. Once triggered, the model assumes that six mechanical trip passes would occur during the year. The triggering factors for mechanical removal in the model reflect criteria in the decision protocol outlined in Reclamation's Nonnative Fish Control EA (Reclamation 2011b). Under Alternative D, mechanical removal of nonnative fish would be implemented in the Little Colorado River reach if Tier 1 conservation actions actions failed to reverse declining trends in humpback chub populations and adult abundance dropped below 7,000. If triggered, mechanical removal efforts would cease if a calculated relative predator index (see Appendix O) declined to 60 rainbow trout per kilometer for 2 years, or if the number of humpback chub exceeded 7,000.

Technical details about the coupled rainbow trout-humpback chub model are presented in Appendix F. The combined model uses an age-structured population dynamics model to predict the abundance and growth of rainbow trout in Glen Canyon, and the number of those fish that migrate into Marble Canyon. The model makes predictions on an annual time step for fish that are 1 to 6 years of age. Annual recruitment (i.e., the number of age-0 fish that enter the population in a given year) is predicted based on flow statistics, and annual growth is predicted as a decreasing function of overall rainbow trout abundance. Abundance, in combination with estimates of age-specific angling vulnerabilities, is used to make predictions of angling catch rates and predicted abundance and size distributions are used to compute the number of quality-sized fish (i.e., trout ≥16 in. total length) potentially available for capture in the fishery. The number of fish migrating into Marble Canyon each year (out-migrants) is predicted as a proportion of the previous year's recruitment, and is used as an input in a submodel that estimates the potential number of fish that eventually migrate down to the confluence of the

Little Colorado River, where their effects on humpback chub are simulated in the humpback chub submodel. Basic parameters and those for key functional relationships in the trout submodel were derived or fitted to values from a stock synthesis model developed by Korman et al. (2012). That model used 21 years of electrofishing-based catch-per-effort data for Glen and Marble Canyons, in conjunction with length frequencies and considerable auxiliary information, to estimate annual recruitment, survival rate, growth parameters, and outmigration patterns for rainbow trout.

As with most models of biological systems, a number of simplifications and assumptions were made in the rainbow trout-humpback chub model. The model was tested by comparing predictions of key state variables such as recruitment, outmigration, and size at the terminal age generated using flow statistics from the historical record between 1990 and 2010 with observations and best estimates of those values for the same period. Predictions of angling catch rates were compared to annual estimates derived from creel surveys (Makinster et al. 2011). Predictions of rainbow trout abundance were compared to interannual trends from electrofishing surveys conducted by the AZGFD. Predictions of recruitment, asymptotic length, and outmigration were compared to best-fit estimates from a stock synthesis model developed by Korman et al. (2012). Overall, the predictions generated by the model resulted in a relatively good fit to historic observations and estimates.

Water temperature is a major factor affecting the distribution and abundance of fish through effects on reproduction, growth, and survival (Valdez and Speas 2007). A temperature model (Wright, Anderson et al. 2008) was used to estimate alternative-specific downstream temperatures and determine their suitability to support reproduction, growth, and survival of nonnative fish (specifically, rainbow and brown trout, smallmouth bass, green sunfish, channel catfish, and striped bass) at locations downstream of Glen Canyon Dam. The temperature suitability model assumed that the potential for self-sustaining populations of nonnative fish at specific locations is related to the combined suitability of temperatures for spawning, egg incubation, and growth of each species. Possible values for temperature suitability can theoretically range from 0 (completely unsuitable for one or more life history aspects) to 1 (magnitude and timing of temperatures would be optimal for all life history aspects). The temperature suitability modeling evaluates the potential for all life history needs to be met in the mainstem river, but some species are known to use tributaries for spawning, incubation, and growth. Thus, the model predicts relatively low temperature suitability even in some areas where species populations appear to be self-sustaining. In addition, modeled temperatures do not consider the potential for warming near tributary mouths or in shallow nearshore areas. Thus, the results of temperature suitability modeling should be used to compare relative effects of alternatives on species-specific temperature needs in the mainstem Colorado River, rather than as an exact predictor of the potential for the presence or absence of nonnative fish species at particular locations.

The distribution and abundance of nonnative fish also can be influenced by the effects of flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal ponding of tributary mouths, sediment transport and deposition, and food base characteristics (Section 3.5.3). Alternative-specific flows were evaluated to assess their effects on these parameters.

4.5.1.3 Native Fish

The assessment of impacts on native fish considered the effects of alternative-specific differences in mainstem flow, water temperature, and sediment regimes on the following:

- The potential for the establishment of self-sustaining populations of native fish at selected mainstem locations;
- Changes in potential levels of competition and predation from nonnative fish;
- Potential increases in parasite infestations; and
- Main channel and nearshore habitat quality, quantity, and stability.

The evaluation of potential impacts of the alternatives on native fish included consideration of the results of previous investigations conducted below Glen Canyon Dam that examined the status and abundance of native fish (e.g., Coggins and Walters 2009; Albrecht et al. 2014; Gerig et al. 2014), as well as studies of the effects of experimental flows (such as HFEs and other flows) and water temperature on native fish (e.g., Makinster et al. 2011; Korman et al. 2010; Ward 2011; Ward and Morton-Starner 2015).

The coupled rainbow trout–humpback chub model described in Section 4.5.1.2 was also used to evaluate potential effects of alternatives on the humpback chub population in the Little Colorado River aggregation over the 20-year LTEMP period. The model estimated survival, growth, and abundance of adult humpback chub based on water temperatures and the estimated abundance of rainbow trout in the Little Colorado River reach, as well as previously reported rates (Yackulic et al. 2014). The effects of triggered mechanical removal and TMFs on trout abundance also were modeled (see Section 4.5.1.2). In order to evaluate the potential for operational scenarios to lead to extinction or improvement of the humpback chub population in the Grand Canyon, the modeled estimate of the minimum number of adult humpback chub that would occur during each 20-year simulation period was compared among alternatives.

Technical details about the humpback chub submodel are provided in Appendix F. The humpback chub submodel was based on the best available scientific information. As presented in Appendix F, the model provided a good fit between simulated adult humpback abundance and abundance estimates developed by Coggins and Walters (2009) for a period of time (1990–2008) that is separate from the period of time (2009–2013) over which most parameters were estimated. However, like all models, it is a simplified representation of the actual system it seeks to describe.

Water temperature is an important factor that affects the distribution and abundance of native fish through its effects on reproduction, growth, and survival (Valdez and Speas 2007). Species-specific models were used to estimate temperature suitability for native fish (including humpback chub) using the same methods and assumptions described in Section 4.5.1.2. As mentioned in that section, the results of temperature suitability modeling should be used to compare relative effects of alternatives on species-specific temperature needs in the mainstem

Colorado River, rather than an exact predictor of the potential for the presence or absence of native fish species at particular locations.

The distribution and abundance of native fish also can be influenced by the effects of flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal ponding of tributary mouths, sediment transport and deposition, turbidity (which may affect predation rates), and food base characteristics (Section 3.5.3). Alternative-specific flows were evaluated to assess their effects on these parameters.

4.5.1.4 Aquatic Parasites

The potential for fish parasites to expand their distribution within the river and result in infestations of native and nonnative species was examined for each alternative. Species-specific temperature suitability models, together with information on current distribution, life history, and ecological requirements (e.g., McKinney, Robinson et al. 2001; Choudhury et al. 2004; Hoffnagle et al. 2006) were used to predict the potential for each alternative to provide conditions in the mainstem river that could increase the occurrence and abundance of fish parasites at selected locations between Glen Canyon Dam and Lake Mead. The evaluations focused on four parasite species: Asian tapeworm (*Bothriocephalus acheilognathi*), anchor worm (*Lernaea cyprinacea*), trout nematode (*Truttaedacnitis truttae*), and whirling disease (*Myxobolus cerebralis*).

4.5.2 Summary of Impacts

The potential impacts of each alternative on the aquatic food base, trout, warmwater nonnative fish, native fish, and aquatic parasites are summarized in Table 4.5-1 and described in the following sections.

4.5.2.1 Aquatic Food Base

The impacts of LTEMP alternatives on the aquatic food base are expected to be negligible, beneficial, or adverse depending on the alternative. Some operational characteristics may cause both beneficial and adverse impacts (e.g., benthic productivity may increase while drift rates decrease with a reduction in daily fluctuations). The impacts are described in the following sections.

Flow Effects on the Aquatic Food Base

In general, flow effects on the aquatic food base depend on the magnitude of daily flows and the within-day and seasonal variability of those flows. The low-flow channel (permanently wetted area) supports most of the primary and secondary production in regulated rivers (Jones 2013b). Steady flows or reduced fluctuations may create conditions that allow a large standing crop of benthic algae and invertebrates to develop, particularly during spring and summer months (Leibfried and Blinn 1987; Pinney 1991; Shannon et al. 2001). Steady flows may also prevent the daily loss or reduction in size of backwaters. More stable backwaters potentially support increased planktonic and benthic communities (Reclamation 1995; Behn et al. 2010). Steady flows or reduced fluctuations may increase benthic productivity over the long term, which will increase invertebrate drift (the preferred food of fish such as trout and humpback chub that feed in the water column) over the long term (Kennedy, Yackulic et al. 2014).

Alternatives with wider daily fluctuations (e.g., Alternatives B and E) would have greater impacts on the aquatic food base than would those with lower fluctuations. Because of repeated cycles of inundation and exposure, the varial zone does not provide consistent conditions for benthic production. The varial zone also provides poor habitat for species with multiple life history stages (Jones 2013) by dewatering of emergence and oviposition sites (Vinson 2001; Kennedy et al. 2016). In the Glen Canyon Dam tailwaters, *Gammarus* standing stock and fecundity are lower, seasonal recruitment of young is briefer, and fewer young are recruited into the population in the varial zone compared to the permanently wetted zone. In addition, *Gammarus* mortality increases in the varial zone (Angradi and Kubly 1993; Ayers and McKinney 1996; Ayers et al. 1998).

Flow fluctuations may increase the amount of organisms available to drift-feeding fish, although this may only occur for a short period (e.g., a few days or less), depending on the density and replacement capacity of benthic invertebrates. For example, a twofold daily variation in discharge resulted in a more than tenfold increase in drift concentrations of *Gammarus* and New Zealand mudsnails, while blackfly drift concentrations decreased by over 80% as discharge doubled. Midge drift concentrations increased proportionally to discharge (Kennedy et al. 2014).

Flows up to 31,500 cfs do not have a large scouring effect on the aquatic food base downstream of Glen Canyon Dam, whereas flows of 41,000 to 45,000 cfs may scour a large portion of the aquatic food base (Reclamation 2011b). The highest mean daily flows for most alternatives would be <14,700 cfs (in an 8.23-maf year), except under Alternative F, which would have mean daily flows of 20,000 cfs in May and June. Thus, aquatic food base scouring would not be expected from base operations regardless of alternative. All alternatives would have HFEs of 45,000 cfs that would last up to 96 hr, while the lengthiest 45,000 cfs HFEs would be 250 hr for Alternative D and 336 hr for Alternative G. Scouring of the aquatic food base by HFEs would be expected for all alternatives. The potential extent of benthic scouring, and the subsequent length of time needed for recovery of the aquatic food base, would be higher with longer duration 45,000-cfs HFEs. In addition, the number and frequency of HFEs may affect scouring and subsequent recovery of the aquatic food base. Table 4.5-2 summarizes the impact on the aquatic food base from HFEs from Glen Canyon Dam that occurred between 1996 and 2008. The March 2008 HFE reduced the biomass and coverage of aquatic macrophytes. This restructured the invertebrate community in favor of fast-growing insect taxa (e.g., chironomids and blackflies) that prefer bare substrates, while disadvantaging non-insect taxa such as New Zealand mudsnails that prefer macrophyte beds (Cross et al. 2011). In subsequent years (2009–2012), aquatic macrophytes restablished, New Zealand mudsnails became dominant, and chironomids and blackflies declined (Gimbel 2015). Preliminary results indicate that recent fall HFEs have not elicited the kind of food base response observed in March 2008. It is possible that

TABLE 4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology

Aquatic Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Compared to Alternative A, slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows; habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced; lower trout abundance; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; habitat quality and stability for nonnative and native fish may be higher; higher trout abundance even with implementation of TMFs and mechanical removal; no difference in humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; experimental macroinvertebrate production flows may further increase productivity and diversity; habitat quality and stability for nonnative and native fish are expected to be slightly higher; negligible change in trout abundance with implementation of TMFs, and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base, and similar or increased drift; habitat quality and stability for nonnative and native fish would be slightly lower; lower trout abundance with implementation of TMFs and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year; positive effects on nonnative and native fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives; higher trout abundance; slightly lower humpback chub abundance.	Compared to Alternative A, relatively high productivity of aquatic food base and long-term drift; greater habitat stability for nonnative and native fish; higher trout abundance even with implementation of TMFs and mechanical removal; slightly lower humpback chub abundance.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Food Base							
Mainstem benthic productivity	No change from current conditions until 2020; no HFEs after 2020 may lower blackfly and midge production.	Compared to Alternative A, slightly lower benthic production due to higher daily flow fluctuations; infrequent HFEs may decrease blackfly and midge production.	Compared to Alternative A, potential increase in benthic production due to more uniform monthly flows from December through August, lower daily range in flows, and more frequent HFEs (which may increase blackfly and midge production).	Compared to Alternative A, potential increase in benthic production due to more uniform monthly flows and more frequent HFEs (which may increase blackfly and midge production); experimental macroinvertebrate production flows may also increase productivity and diversity.	Compared to Alternative A, potential increase in benthic production due to more uniform monthly flows and more frequent HFEs (which may increase blackfly and midge production), but increase would be offset by higher within-day flow fluctuations.	Compared to Alternative A, potential increase in benthic production in spring and early summer from increased monthly flows with no daily flow fluctuations, but lower rest of year due to low steady flows; frequent HFEs may increase blackfly and midge production.	Compared to Alternative A, benthic production relatively high and consistent throughout the year due to relatively stable monthly flows with no daily flow fluctuations, but this may favor species that lack a terrestrial adult stage; frequent HFEs may increase blackfly and midge production.
Drift	No change from current conditions.	Compared to Alternative A, increased drift due to higher within-day fluctuations.	Compared to Alternative A, increased drift due to increased benthic production.	Compared to Alternative A, increased drift due to increased benthic productivity. Higher weekday flows following experimental macroinvertebrate production flows may temporarily increase drift.	Compared to Alternative A, increased drift due to higher within-day fluctuations.	Compared to Alternative A, increased drift due to increased benthic production.	Compared to Alternative A, increased drift due to increased benthic production.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Food Base (Cont.)							
Nearshore benthic productivity	No change from current conditions and levels, although no HFEs after 2020 may adversely affect backwater establishment.	Compared to Alternative A, potentially lower nearshore productivity due to higher daily range in flow; infrequent HFEs throughout the LTEMP period may slightly improve backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity from lower daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity based on more uniform monthly release volumes; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, nearshore productivity slightly lower based on somewhat higher daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity from no daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity from no daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.
Trout							
Spawning habitat	No change from current conditions.	Compared to Alternative A, potential decrease in spawning habitat availability and stability due to higher within-day flow fluctuations during the spawning period.	Compared to Alternative A, potential increase in spawning habitat availability and stability due to lower within-day flow fluctuations during the spawning period.	Compared to Alternative A, slight potential decrease in spawning habitat availability and stability due to slightly greater within-day flow fluctuations during the spawning period.	Compared to Alternative A, lowest spawning habitat availability and stability due to highest average within-day flow fluctuations during the spawning period.	Compared to Alternative A, spawning habitat relatively available and stable within spring months due to absence of within-day flow fluctuations, but high flows in May and June affect availability and stability.	Compared to Alternative A, greatest spawning habitat availability and stability due to absence of within-day flow fluctuations and even monthly distribution of flows.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Trout (Cont.)							
Stranding	No change from current conditions and levels.	Compared to Alternative A, greatest potential for increased stranding resulting from highest down-ramp rate.	Compared to Alternative A, potential increase due to higher down-ramp rate.	Compared to Alternative A, potential increase due to higher down-ramp rate.	Compared to Alternative A, potential increase due to higher down-ramp rate.	Compared to Alternative A, relatively low potential for stranding due to absence of within-day flow fluctuations, but large drops in flow would occur after high flows in May and June.	Compared to Alternative A, lowest potential for stranding due to absence of within-day flow fluctuations and even monthly distribution of flows.
Population size in Glen Canyon reach	No change from current conditions and levels. Estimated mean abundance 95,000 age-1 and older fish.	Compared to Alternative A, small potential decrease compared to Alternative A. Estimated abundance 74,000 age-1 and older fish.	Compared to Alternative A, small potential increase because of frequent HFEs and lower daily flow fluctuations. Estimated mean abundance 102,000 age-1 and older fish.	Compared to Alternative A, negligible change. Estimated mean abundance 93,000 age-1 and older fish.[a]	Compared to Alternative A, small potential decrease because of higher flow fluctuations. Estimated mean abundance 88,000 age-1 and older fish.	Compared to Alternative A, greatest potential increase among all alternatives because of frequent HFEs and steady flows. Estimated mean abundance 160,000 age-1 and older fish.	Compared to Alternative A, potential increase because of frequent HFEs and steady flows. Estimated mean abundance 132,000 age-1 and older fish.
Number of fish >16 in. total length (TL) in Glen Canyon reach	No change from current condition. Estimated abundance 770 fish.	Compared to Alternative A, potential increase because higher fluctuations and relatively few HFEs lower recruitment and reduces competition. Estimated mean abundance 870 fish.	Compared to Alternative A, negligible change. Frequent HFEs and lower fluctuations increase recruitment but TMFs control trout numbers. Estimated mean abundance 750 fish.	Compared to Alternative A, negligible change. Frequent HFEs increase recruitment but TMFs control trout numbers. Estimated mean abundance 810 fish.	Compared to Alternative A, potential increase because of higher fluctuations, few spring HFEs, and implementation of TMFs lower recruitment and reduces competition. Estimated mean abundance 830 fish.	Compared to Alternative A, greatest potential decrease because steady flows, annual spring HFEs, and no TMFs result in high recruitment and increased competition. Estimated mean abundance about 600 fish.	Compared to Alternative A, potential decrease.. Steady flows and frequent HFEs result in high recruitment and increased competition, but TMFs offset increases. Estimated mean abundance about 700 fish.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Trout (Cont.)							
Emigration from Glen Canyon to Marble Canyon	No change from current conditions. Estimated mean emigration about 37,000 fish/yr.	Compared to Alternative A, lowest potential emigration because higher fluctuations and relatively few HFEs lower recruitment. Estimated mean emigration about 30,000 fish/yr.	Compared to Alternative A, potential increase in emigration. Frequent HFEs and lower fluctuations increase recruitment. Estimated mean emigration about 44,000 fish/yr.	Compared to Alternative A, potential increase in emigration. Frequent HFEs increase recruitment, but offset by fluctuations and TMFs. Estimated mean emigration about 41,000 fish/yr.[a]	Compared to Alternative A, negligible change; fewer spring HFEs, higher fluctuations, and TMFs result in low recruitment. Estimated mean emigration about 38,000 fish/yr.	Compared to Alternative A, highest potential emigration. Annual spring HFEs, steady flows, and lack of TMFs result in high recruitment. Estimated mean emigration about 72,000 fish/yr.	Compared to Alternative A, potential increase in emigration. Steady flows and frequent HFEs result in high recruitment, but TMFs offset increases. Estimated mean emigration about 59,000 fish/yr.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Compared to Alternative A, some improvement in suitability at RM 61 but reduced suitability at RM 157 and RM 225.	Similar to Alternative A.
Warmwater Nonnative Fish							
Nearshore habitat quality, availability, and stability	No change from current levels and conditions.	Compared to Alternative A, possible decrease due to highest ramp rates and within-day flow fluctuations of all alternatives.	Compared to Alternative A, potential increase associated with lower within-day fluctuations.	Compared to Alternative A, potential increase in habitat availability and stability based on more uniform monthly release volumes.	Compared to Alternative A, possible decrease due to higher within-day fluctuations in most months.	Compared to Alternative A, possible increase resulting from elimination of within-day flow fluctuations.	Compared to Alternative A, possible increase resulting from elimination of within-day flow fluctuations.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Parasites							
Potential for increased establishment and infestation	No change from current conditions and levels.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.
Native Fish							
Humpback chub population size	No change from current levels. Estimated average minimum number of adults about 5,000; estimated lowest minimum number of adults about 1,500.	Compared to Alternative A, greatest potential increase resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,400; estimated lowest minimum number of adults about 1,900; higher fluctuations could reduce food base productivity and limit chub numbers.	Compared to Alternative A, negligible change. Estimated average minimum number of adults 5,000; estimated lowest minimum number of adults about 1,500.	Compared to Alternative A, potential increase resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,200; estimated lowest minimum number of adults about 1,800; potential increase in food base productivity could favor chub.	Compared to Alternative A, potential increase resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,300; estimated lowest minimum number of adults about 1,600; higher fluctuations could reduce food base productivity and limit chub numbers..	Compared to Alternative A, greatest potential decrease resulting from highest increases in trout recruitment. Estimated average minimum number of adults about 4,400; estimated lowest minimum number of adults about 1,400; potential increase in food base productivity could offset some adverse impacts on chub.	Compared to Alternative A, potential decrease resulting from increased trout recruitment. Estimated average minimum number of adults about 4,700; estimated lowest minimum number of adults about 1,700; potential increase in food base productivity could offset some adverse impacts on chub.
Temperature suitability for humpback chub at aggregation locations	No change from current levels at all locations.	Similar to Alternative A.	Compared to Alternative A, small potential reduction.	Similar to Alternative A.	Compared to Alternative A, small potential reduction.	Compared to Alternative A, greatest potential reduction.	Similar to Alternative A.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Native Fish (Cont.)							
Humpback chub growth in main channel	Negligible change from current conditions. Estimated growth of YOY humpback chub in mainstem about 24 mm at RM 61 and about 50 mm at RM 213.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Compared to Alternative A, but greatest potential increase. Estimated growth of YOY humpback in mainstem about 26 mm at RM 61 and about 54 mm at RM 213.	Similar to Alternative A.
Temperature suitability for other native fish	Negligible change from current levels at all locations.	Similar to Alternative A.	Similar to Alternative A.	Compared to Alternative A, small potential increase at downstream locations.	Similar to Alternative A.	Compared to Alternative A, small decrease at RM 225.	Compared to Alternative A, slight potential increase at downstream locations.
Interactions between native and nonnative fish	Negligible change from current levels for most species	Compared to Alternative A, negligible change for most species. Possible decrease in humpback chub–rainbow trout interactions with reduced trout emigration to Marble Canyon reach.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative B.	Compared to Alternative A, possible increase in interactions with warmwater nonnative fish at downstream locations, highest rainbow trout emigration to Marble Canyon among all alternatives may adversely affect humpback chub.	Compared to Alternative A, possible increase in interactions with warmwater nonnative fish at downstream locations, highest rainbow trout emigration to Marble Canyon among all alternatives may adversely affect humpback chub.

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[a] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition (1.3 fewer), and this reduction in frequency could reduce the number of trout produced under Alternative D.

TABLE 4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic Food Base

High Flow Experiment	Impact on Aquatic Food Base
45,000 cfs for 7 days, March 26–April 2, 1996	Scouring; 3- to 4-month reduction in abundance and biomass
31,000 cfs for 3 days, November 5–7, 1997	No effects detected
31,000 cfs for 3 days, May 2–4, 2000	No effects detected
31,000 cfs for 3 days, September 4–6, 2000	Some taxa and reaches affected; recovery period not determined
41,000 cfs for 2.5 days, November 21–23, 2004	Possible delayed recovery because HFE occurred in the fall after the growing season
41,500 cfs for 2.5 days, March 5–7, 2008	Reduced biomass of some taxa (e.g., New Zealand mudsnails and *Gammarus*) persisted for >1 year; enhanced drift biomass of some taxa such as midges and blackflies associated with their increased benthic production that lasted >1 year

Source: Reclamation (2011b); Cross et al. (2011).

in the fall, macrophytes and non-insect invertebrates are more resistant to disturbance than they are in spring; however, repeated fall HFEs may shift the food base to a new equilibrium (Kennedy et al. 2015). It is also possible that fall HFEs temporarily reduce macrophyte cover, but that it recovers the following spring. Thus, timing rather than magnitude appears to be the main factor affecting the response of the aquatic food base to HFEs (Gimbel 2015).

The seasonal timing of HFEs (i.e., spring vs. fall) may influence the magnitude of ecological response and recovery rates of ecosystem processes. Recovery times are generally shorter for spring HFEs than for fall HFEs as a result of longer day lengths and warmer river temperatures in spring and summer. Fall HFEs precede winter months of minimal insolation, low temperatures, and reduced gross primary productivity (Cross et al. 2011). HFEs are expected to favor production of midges and blackflies within the Glen Canyon Dam tailwaters, apparently because the short-term adverse effects of scouring lead to an increase in future habitat quality for these organisms (Cross et al. 2011). In addition, although an HFE could reduce total invertebrate production, it may increase the amount of invertebrate prey available to rainbow trout by shifting the invertebrate assemblage toward species that are prone to drift (Cross et al. 2011). Fewer HFEs would occur under Alternatives A and B (Table 4.3-1). Therefore, these alternatives are not expected to cause long-term changes in invertebrate production due to HFEs, but neither would they favor the production of midges and blackflies in the short term after the HFE. The other five alternatives would have HFEs frequent enough to alter mainstem benthic productivity, which favors blackfly and midge production (Table 4.5-1).

Understanding the cumulative effects of multiple HFEs will be an important consideration of the experimental plan for all alternatives. More frequent HFEs in the Grand Canyon could cause a shift to more scour-resistant taxa, resulting in an overall decrease in macroinvertebrate diversity, and possibly abundance, resulting in a reduction in the aquatic food base (Reclamation 2011a). Fishing guides working in Lees Ferry report that *Gammarus* is less abundant now than it was in the 1980s. While scientific studies do not support these observations, it is possible that declines have not been detected by benthic invertebrate studies that first started in the 1990s (Kennedy 2016). Although HFEs could be a causative agent in a decline of *Gammarus*, other causes are more plausible, especially predatory losses associated with dramatic trout density increases since the 1980s (Kennedy 2016). Humpback chub dietary studies suggest that *Gammarus* abundance may have declined in the area of the Little Colorado River. *Gammarus* comprised about 40% of the humpback chub diet in the early 1990s (Valdez and Ryel 1995), but only 2% of their diet in 2008 (Cross et al. 2013). However, the decline of *Gammarus*, at least as a component of humpback chub diet, does not seem to have been detrimental to the fish (i.e., the humpback chub population declined in the early 1990s but increased by 2008) (Kennedy 2016). See Section F.2.2.1 (Appendix F) for a discussion of potential effects of frequent HFEs on the aquatic food base.

TMFs would be tested under Alternatives B, C, D, E, and G. During the high-flow portions of TMF cycles, drift rates should increase, making more food available to trout and other fish. The very brief (less than 1 day) low-flow portion of TMF cycles are expected to have minor effects on the production of aquatic invertebrates because substrates would be exposed for such a short period of time. No TMFs would occur under Alternative F, and TMFs would only be tested under Alternative A (No Action Alternative). TMFs would be tested and implemented, if tests are successful, for the other alternatives.

A more thorough discussion of potential flow effects on the aquatic food base is provided in Appendix F.

Temperature Effects on the Aquatic Food Base

The species composition, diversity, and production of the aquatic food base in the Colorado River could change in response to water temperature variations (Stevens, Shannon et al. 1996; Valdez et al. 2000). Blinn et al. (1989) observed that epiphytic diatom communities, which serve as an important food source for macroinvertebrates and some fish, change from upright (stalked) diatoms to closely adnate diatoms (those that grow flat on the substrate) with an increase in water temperature from 12 to 18°C (54 to 64°F). This is an important consideration because adnate forms of diatoms are generally more difficult for macroinvertebrates and fish to consume compared to stalked diatoms.

Temperature modeling results (Section 4.1.2.3) indicate that mean monthly temperatures over the 20-year LTEMP period for all alternatives will be ≤14.1°C (57.4°F) at Lees Ferry (RM 0) and the confluence with the Little Colorado River (RM 61). Thus, temperature differences among the alternatives are not expected to alter the diatom composition in the Glen Canyon or Marble Canyon reaches of the Colorado River. However, at Diamond Creek RM 225 (Grand Canyon reach), mean summer temperatures (July through September) for all alternatives would be high enough (e.g., ≥17°C [63°F]) to potentially favor adnate diatom species (see Table F-5, Appendix F). Mean monthly temperatures at Diamond Creek would be highest for Alternative F ranging from 18.5 to 20.5°C (65.3 to 68.9°F) and least for Alternatives A and B ranging from 17.2 to 17.5°C (63.0 to 63.5°F). However, increased algae production in the Grand Canyon reach, may not be realized because this reach is strongly light-limited due to higher turbidity levels.

Section 3.5.2 describes the improved aquatic food base conditions provided by *Cladophora* compared to *Oscillatoria* (types of algae). Light and flow conditions are the primary factors that affect the presence of these organisms in the Colorado River even though modeled monthly temperatures near Lees Ferry and the Little Colorado River otherwise favor the presence of *Cladophora*, which has a favorable temperature range of 13 to 17°C (55 to 63°F), compared to *Oscillatoria*, which has a favorable temperature range of 18 to 21°C (64 to 70°F) (Valdez and Speas 2007). This also applies to the Diamond Creek area, although modeled water temperature conditions in late spring and summer would favor *Oscillatoria* over *Cladophora* for all alternatives, particularly Alternative F where monthly summer temperatures would range from 18.6 to 20.5°C (65.5 to 68.9°F) (see Table F-5, Appendix F). Because conditions at Diamond Creek are already more suitable for *Oscillatoria* (which is more tolerant of turbidity) than *Cladophora*, it would remain more prevalent in the Grand Canyon reach.

The modeled mean monthly temperatures in the Colorado River downstream of Glen Canyon Dam are within the favorable temperature range for most macroinvertebrates (see Table F-7, Appendix F). However, the modeled mean monthly temperatures for all alternatives for January through April range from 8.7 to 9.9°C (47.7 to 49.8°F) at Lees Ferry, which is below the lowered favorable temperature of 10°C (50°F) for blackflies (Valdez and Speas 2007). The modeled mean monthly temperatures would also be below favorable temperatures for blackflies near the Little Colorado River for February and March. Conversely, modeled monthly temperatures of 17.2 to 20.5°C (63.0 to 68.9°F) for July through August near Diamond Creek under all alternatives would be higher than the upper favorable temperature for planarians 16°C (61°F) (Valdez and Speas 2007).

Production rates of macroinvertebrates could increase by 3 to 30% for every 1°C (1.8°F) increase in annual temperatures (Valdez and Speas 2007). Temperature modeling results indicate that annual average temperatures would vary among alternatives by ≤0.2°C (0.4°F) at Lees Ferry, Little Colorado River, and Diamond Creek. This implies that temperature differences among alternatives are not likely to affect production of aquatic food base organisms. However, comparison of monthly average temperatures indicates a potential small difference among some of the alternatives during the summer at Diamond Creek. Most temperature differences among alternatives would be <0.5°C (0.9°F) and therefore not considered significant. However, Alternative F would be as much as1.5 to 3.0°C (2.7 to 5.4°F) higher than the other alternatives in the summer. Thus, summer macroinvertebrate productivity could be higher under Alternative F compared to the other alternatives.

A more thorough discussion of potential temperature effects on the aquatic food base is provided in Appendix F.

4.5.2.2 Nonnative Fish

The potential impacts of the alternatives on nonnative fish are described in this section and summarized in Table 4.5.2-1. Because of distinct differences in habitat needs and distributions, impacts on coldwater nonnative fish (trout) and warmwater nonnative fish are considered separately.

Impacts on Trout

Rainbow trout recruitment and population size within the Glen Canyon reach appear to be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999; McKinney, Speas et al. 2001; McKinney, Robinson et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman, Kaplinski et al. 2011; Korman et al. 2012). Increases in abundance have been attributed to the changes in flows beginning with interim flows in 1991 and later the implementation of MLFF in 1996. These changes both increased minimum flows and reduced fluctuations in daily flows, which created more stable and productive nursery habitats for rainbow trout in Glen Canyon (McKinney et al. 1999). Declines in abundance (such as observed from 2001 to 2007) have been attributed to the combined influence of warmer water releases from Glen Canyon Dam, high abundance and increased competition, and periodic DO deficiencies, along with possible limitations in the food base (Makinster et al. 2007). Increases in recruitment levels and trout abundance in the Glen Canyon reach during 2008 and 2009 are believed to be due to improved habitat conditions and survival rates for YOY rainbow trout resulting from the March 2008 HFE (Makinster et al. 2011).Recruitment of rainbow trout in Glen Canyon has been positively and strongly correlated with annual flow volume and reduced hourly flow variation; recruitment has also increased after two of three high-flow releases related to the implementation of equalization flows (Korman et al. 2012). The abundance of rainbow trout within the Glen Canyon reach affects the condition (a measure of the weight-length relationship, or “plumpness”) of rainbow trout in the population. When abundance of rainbow trout is high, their condition typically deteriorates, so large numbers of fish generally also lead to fish of poorer quality to anglers in terms of size and condition (Makinster et al. 2011) and can also lead to declines in abundance.

Because rainbow trout spawning occurs mostly in the main channel of the Glen Canyon reach, the quality and availability of rainbow trout spawning habitat are expected to be affected by within-day flow fluctuations (McKinney, Speas et al. 2001; Korman, Kaplinski et al. 2011; Korman and Melis 2011), which vary among the alternatives. Within-day flow fluctuations in this reach may act to periodically dewater some spawning areas (redds) while down-ramping may strand larval or YOY rainbow trout (Reclamation 1995; Korman et al. 2005; Korman, Kaplinski et al. 2011; Korman and Melis 2011). Recent captures of young-of-the-year trout in the vicinity of the Little Colorado River confluence suggest that there may be some rainbow trout spawning in lower Marble Canyon; the degree to which spawning and recruitment of trout in this portion of the river might be affected by flow manipulations, including TMFs, is not clear. Mainstem spawning and recruitment of brown trout (*Salmo trutta*) in the Grand Canyon are thought to be limited because of unsuitable temperatures, competition from rainbow trout, and limited availability of suitable habitat for spawning and rearing of YOY trout (Makinster et al.

2010; Reclamation 2011a,b). Because brown trout reproduction primarily occurs in tributaries, especially in Bright Angel Creek (Reclamation 2011a, b), their spawning habitats generally would not be affected by the flows associated with any of the alternatives. The following discussion focuses on potential effects of the alternatives on rainbow trout.

Evaluation of the stability of rainbow trout spawning habitat for each of the alternatives considered the average allowable daily fluctuation and the evenness of the monthly volumes during the peak spawning months (March through May). Under Alternative A, no changes from current conditions are expected in spawning habitat availability or stability. Rainbow trout spawning habitat would be less stable under Alternatives B and E than under Alternative A because both would allow greater levels of within-day fluctuations during the peak spawning months. Alternative E is expected to have the lowest stability since daily fluctuations and variation in monthly volumes are slightly greater than under Alternative B during the peak spawning months. Compared to Alternative A, Alternatives D and C would have lower allowable within-day fluctuations, similar or greater monthly volumes, and less variable monthly volumes during the spawning period; as a consequence, rainbow trout spawning habitat availability and stability under Alternatives D and C would be higher than under Alternative A. The two steady flow alternatives (Alternatives F and G) would provide the greatest level of spawning habitat stability.

Because of differences in down-ramp rates for base operations (i.e., not considering effects of HFEs and TMFs), the potential for stranding of YOY trout is expected to vary among the alternatives (Table 4.5-1). Potential for stranding under Alternative A is expected to be similar to that under current conditions. Stranding potential under Alternative G would be the lowest since there would be no within-day fluctuations for hydropower generation and relatively small down-ramping events between months. Although Alternative F would also exclude within-day fluctuations for hydropower operations, there would be large drops in flows after the annual 45,000 cfs spike releases that would occur in May and after the week-long 25,000 cfs high flow that precedes the drop to base flows at the end of June; as a consequence, stranding of YOY trout could be significant under this alternative. Compared to Alternative A, the greatest increase in stranding potential would occur under Alternative B, which has down-ramp rates of 3,000 to 4,000 cfs/hr (100% to 166% higher than any of the other alternatives). Alternatives C, D, and E may have a similar increased stranding potential, with down-ramp rates 66% higher than under Alternative A. As noted above, the degree to which spawning and recruitment of trout in lower Marble Canyon (i.e., in the vicinity of the Little Colorado River) might be affected by flow manipulations, including TMFs, is not clear.

As described in Section 4.5.1.2, a coupled rainbow trout–humpback chub model, which considers effects of flow variability, annual volumes, HFEs, and TMFs, and effects of annual trout numbers was used to evaluate potential effects of alternatives on the number and average size (length) of rainbow trout in the Glen Canyon reach, on the number of rainbow trout in the Glen Canyon reach exceeding 16 in. in total length, and on the number of age-0 rainbow trout expected to move into the Marble Canyon and Little Colorado River reaches over the 20-year LTEMP period. Among the alternatives, the model estimated average abundances of age-1 (i.e., individuals that are 1 year old) and older rainbow trout over the 20-year LTEMP period that ranged from about 65,000 to 196,000 individuals in the Glen Canyon reach (Figure 4.5-1).

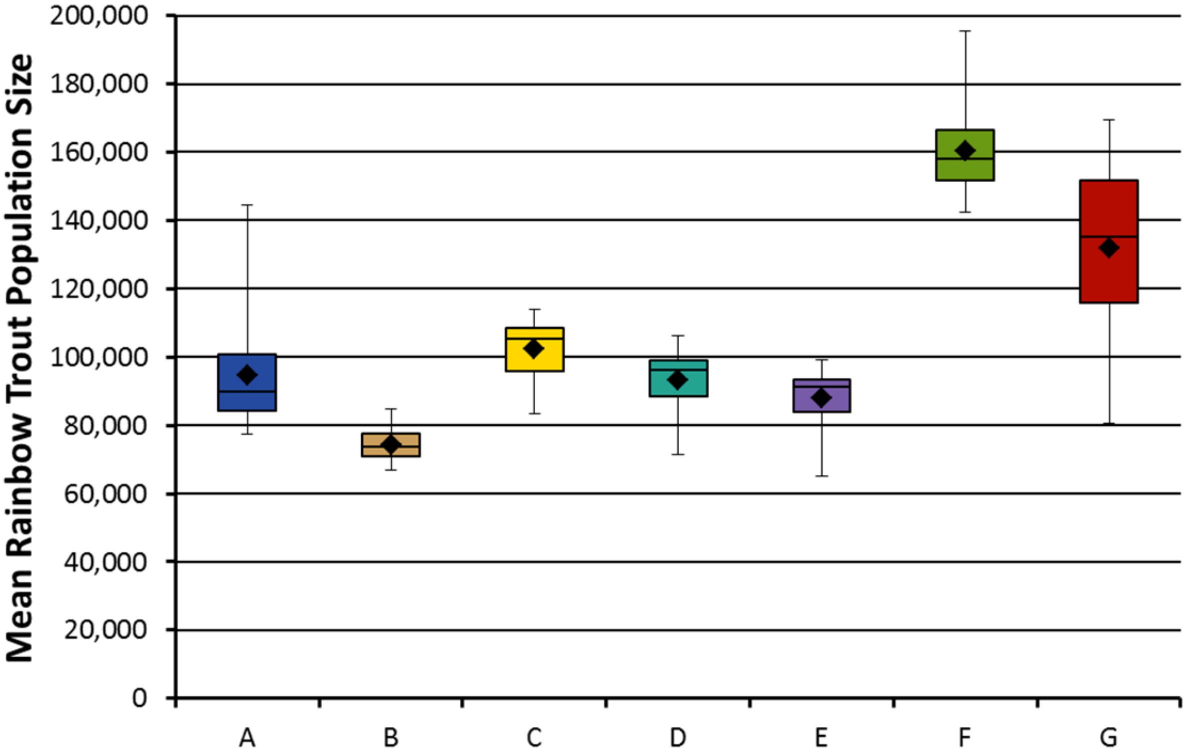

FIGURE 4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum. Means were calculated as the average for all years within each of the 21 hydrology runs.)

Although there is a considerable amount of overlap in the ranges of the estimates for some alternatives, the overall estimated average rainbow trout abundance in the Glen Canyon reach was greatest under Alternatives F and G and lowest under Alternative B, with intermediate abundance levels under Alternatives A, C, D, and E.

The model predicts that annual recruitment of rainbow trout will increase as a function of greater annual volumes, reduced daily variation in flow between May and August, and the occurrence of spring HFEs (see Appendix F). Modeling indicated that alternatives with more frequent HFEs (especially spring HFEs) would have higher recruitment rates. These factors could lead to increased mean abundance of rainbow trout in the Glen Canyon reach and ultimately in the Little Colorado River reach. TMFs and mechanical removal would be used under some alternatives to offset increases in abundance.[9] Because of the effects of trout density

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[9] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

on growth rates due to competition for food and other resources, it is expected that the average size of rainbow trout would decrease as average population size increases (Korman, Kaplinski et al. 2011). Modeling results indicated that the average size of age-1 and older rainbow trout over the LTEMP period would be greatest under Alternative B, smallest under Alternatives F and G, and intermediate under Alternatives A, C, D, and E (see Appendix F).

The results of the trout modeling for LTEMP alternatives are consistent with historic observations and previous research, which suggests that recruitment of rainbow trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in years with HFEs (especially spring HFEs), and in years with lower levels of within-day fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012; Section 3.5.4). Equalization flows, which would occur under all alternatives, are also expected to result in increased rainbow trout recruitment during years in which they occur. The high spring flows of Alternative F and spring HFEs would have similar effects on trout recruitment. Considering the frequency of HFEs alone (Table 4.3-1), average annual rainbow trout recruitment would be expected to be highest under Alternatives C, D, F, and G, and would be lowest under Alternatives A and B. It should be noted, however, that the effects of fall HFEs on trout recruitment are less certain and altering assumptions regarding the strength of the relationship between recruitment levels and fall HFEs could significantly affect the modeled results regarding relative effects of alternatives on average numbers of YOY trout, average numbers of trout emigrating to Marble Canyon, and average abundance of age-1 and older rainbow trout in the Glen Canyon reach during the LTEMP period. Preliminary analyses indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015).

Potential increases in rainbow trout recruitment levels due to equalization flows and HFEs could be offset in some years by the proposed testing and implementation of TMFs for all alternatives except Alternative A and F, which do not include TMFs. TMFs are highly variable flows intended to control the number of YOY trout in the Glen Canyon reach (and the associated emigration of trout into Marble Canyon) that would be implemented in years where production of YOY trout is expected to be high. YOY trout tend to occupy shallow habitats near the channel margin (Korman and Campana 2009; Korman and Melis 2011). Based on information from previous studies, raising the flow for a period of days and then suddenly dropping the flow is expected to strand and kill YOY trout, thus controlling numbers and emigration rates (Korman and Melis 2011). As currently envisioned, a typical TMF would consist of several days at a relatively high sustained flow (e.g., 20,000 cfs) followed by a rapid drop to a low flow (e.g., 5,000 cfs), which is held for a brief period (e.g., 6 hr) (Sections 2.2.3.2). This pattern would be repeated for a number of cycles in spring and summer months (May–July). Because of uncertainties about the effectiveness of TMFs, the timing, magnitude, duration, and number of cycles would be tested for efficacy in controlling trout numbers early in the LTEMP period. The number of TMFs that would be expected to occur under each alternative based on modeling are presented in Table 4.9-3 and in Appendix F (Table F-8).

The number of trout emigrating from the Glen Canyon reach into the Marble Canyon reach of the Colorado River was modeled as a function of recruitment levels, which is related to annual volumes, the occurrence of HFEs, the levels of within-day fluctuations during each water year, and whether TMFs are included as a management option for an alternative. The model estimated that average annual emigration of rainbow trout would be highest under the two steady flow alternatives (Alternatives F [about 72,000 fish/year] and G [about 59,000 fish/year]) and lowest under the alternative with the widest daily fluctuations (Alternative B [about 30,000 fish/year]); the model estimated that Alternatives A, C, D, and E would have intermediate levels of rainbow trout emigration (about 37,000 to 44,000 fish/year) (Figure 4.5-2).

As a measure of the quality of the rainbow trout fishery, the trout model was also used to estimate the average annual number of large rainbow trout (i.e., individuals with total lengths exceeding 16 in.) in the Glen Canyon reach. Among the alternatives, the estimated average number of large rainbow trout in the Glen Canyon reach would range from about 500 to 950 fish (Figure 4.5-3). The estimated average number of large trout present during the 20-year LTEMP period would be greatest under Alternative B (about 870 fish) and lowest under Alternatives F (about 590 fish) and G (about 700 fish), while Alternatives A, C, D, and E would produce intermediate numbers of large trout (about 770, 750, 810, and 830 fish, respectively). In general, growth rates and the number of large rainbow trout in the Glen Canyon reach are expected to be greater in years when overall population abundance is lower due to reduced competition for food and habitat. Because of their effect on recruitment levels and population size, alternatives that

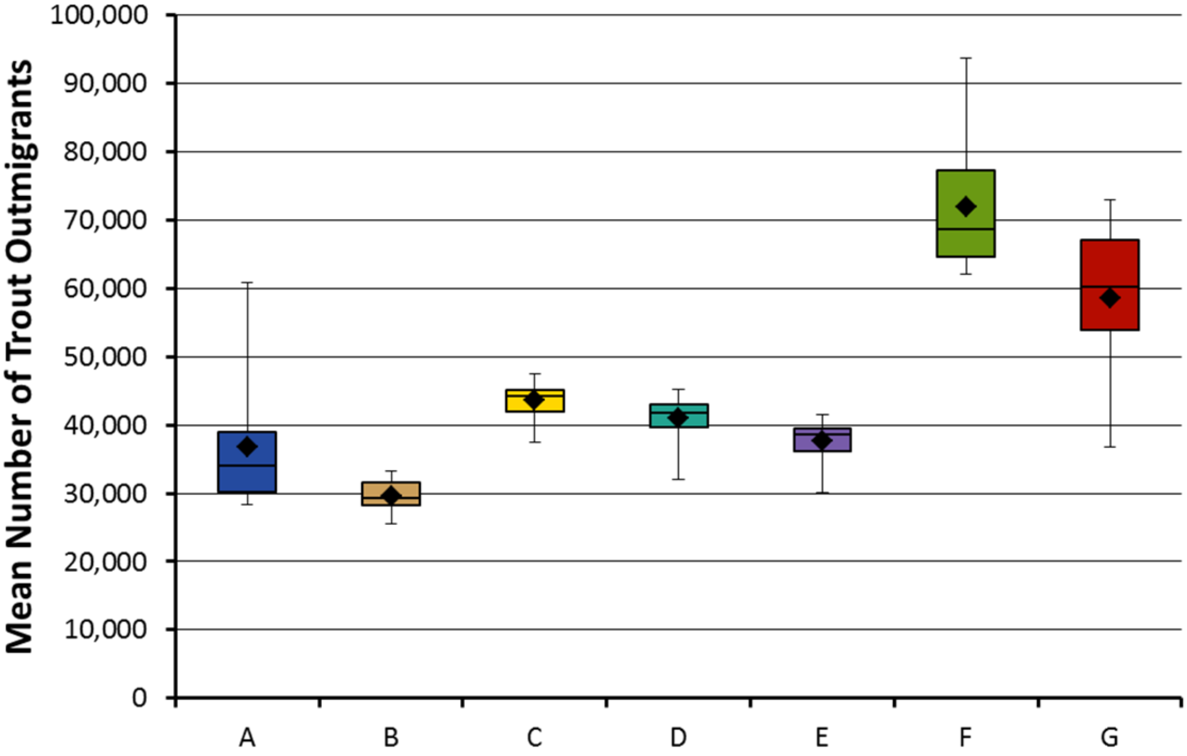

FIGURE 4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

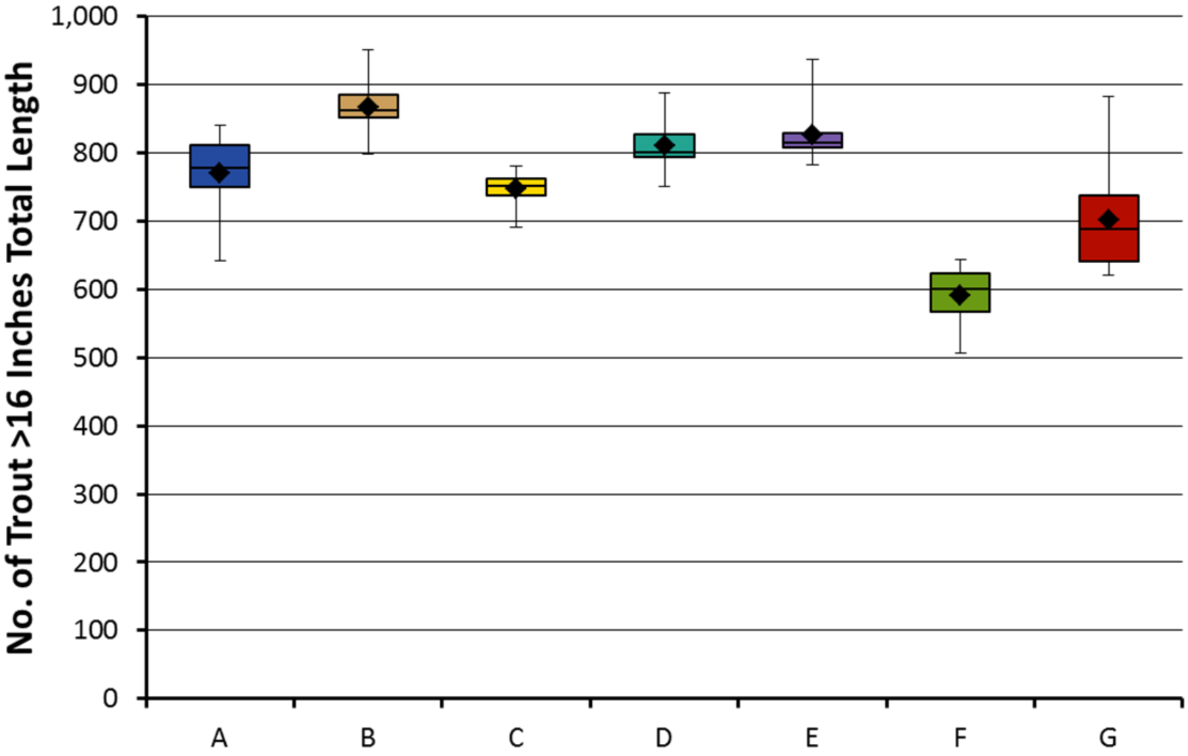

FIGURE 4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during 20-Year Simulation Periods under the LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

have fewer HFEs (especially spring HFEs), higher daily fluctuations, or implement TMFs are expected to have more large trout.

In general, temperature regimes under all of the alternatives would be suitable, although not optimal, for brown and rainbow trout. Temperature suitability for brown and rainbow trout would be similar among alternatives at most locations downstream of Glen Canyon Dam (Figure 4.5-4), and would be similar to current conditions. However, because of the timing of peak and base flow releases, temperature suitability would be slightly greater under Alternative F than other alternatives at the confluence with the Little Colorado River (RM 61) and lower than other alternatives for locations further downstream. Although main channel temperatures at and downstream of RM 61 would be more suitable for trout than at locations closer to the dam (Figure 4.5-4), the abundance of trout is lower at those locations because other habitat characteristics (e.g., substrate composition and water clarity) are less suitable at these downstream locations.

Low summer flows included under Alternatives C, D, and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitats. Providing warmer nearshore habitats could promote recruitment and survival of trout that prey

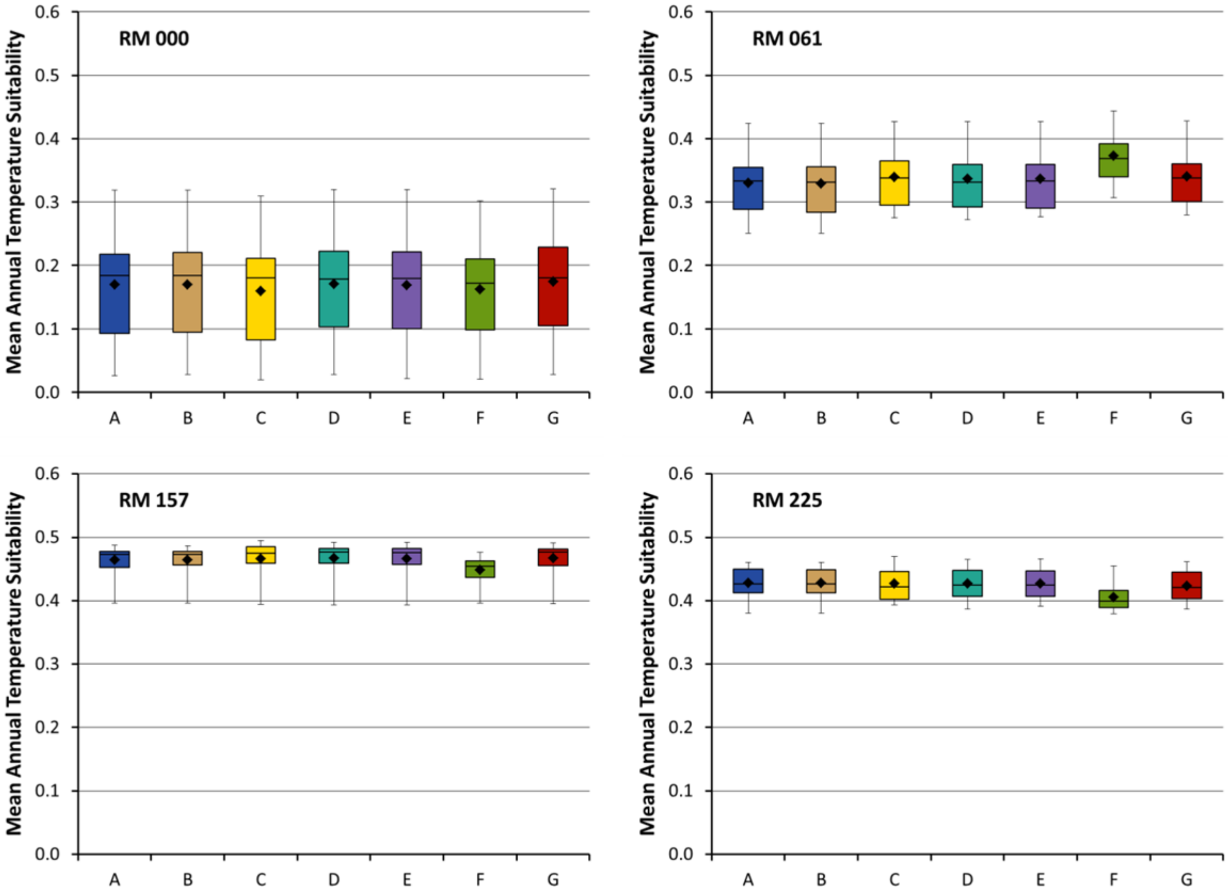

FIGURE 4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

on or compete with native fish species. Because temperature suitability under normal operations is lower than optimal for rainbow and brown trout (Figure 4.5-4), warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach that is important for humpback chub. However, effects on trout and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout and native fish were anticipated.

Impacts on Warmwater Nonnative Fish

As described in Section 3.5.4.2, 17 nonnative warmwater fish species have been documented between Glen Canyon Dam and the inflow to Lake Mead (Table 3.5-2). The distribution and abundance of warmwater nonnative fish could be affected by alternative-specific differences in temperature regimes, food production, sediment dynamics, and flow patterns. As described in Section 4.5.2.1 and Appendix F, alternatives could affect food production for both native and nonnative fish downstream of Glen Canyon Dam. Changes in sediment regimes and flows under the alternatives could affect the suitability of conditions for warmwater nonnative fish, especially in nearshore habitats (Table 4.5-1).

Temperature suitability was modeled at various main channel locations for four nonnative warmwater species considered to be representative of the warmwater nonnative fish community (smallmouth bass [*Micropterus dolomieu*], green sunfish [*Lepomis cyanellus*], channel catfish [*Ictalurus punctatus*], and striped bass [*Morone saxatilis*]). In general, the estimated average main channel temperature suitability for these nonnative fish did not differ greatly among the alternatives, and was low under all alternatives; the suitability index was below 0.2 on a scale of 0 to 1 for all seven alternatives (Figure 4.5-5). The modeled temperature suitability indicated that temperature conditions would be most suitable for warmwater nonnative species at locations farther downstream from Glen Canyon Dam (e.g., RM 157 and RM 225) compared to upstream locations (e.g., RM 0 and RM 61); this agrees with past surveys that have found more warmwater nonnative fish species in those areas. Relative to current conditions (as exemplified by Alternative A), the temperature suitability model indicated that Alternatives C and F have the greatest potential to improve conditions for warmwater nonnative fish at locations downstream of RM 157, which could result in increased numbers and a greater potential for upstream spread of warmwater nonnative fish species.

Low summer flows included under Alternatives C, D, and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitats. Providing warmer nearshore habitats could promote recruitment and survival of warmwater nonnative fish species that prey on or compete with native fish species. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. However, effects on warmwater nonnative and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

The Basin Study (Reclamation 2012a) suggested there could be significant increases in temperature and decreases in water supply to the Colorado River system below Glen Canyon Dam over the next 50 years, driven by global climate change. The magnitude of these changes is uncertain. Water elevations in Lake Powell could continue to decline, resulting in release of unprecedentedly warm epilimnetic and metalimnetic water through the penstocks. Summer water releases of up to 30°C water could facilitate establishment of detrimental warmwater fish with correspondingly detrimental impacts on native species, including humpback chub, and on the rainbow trout fishery.

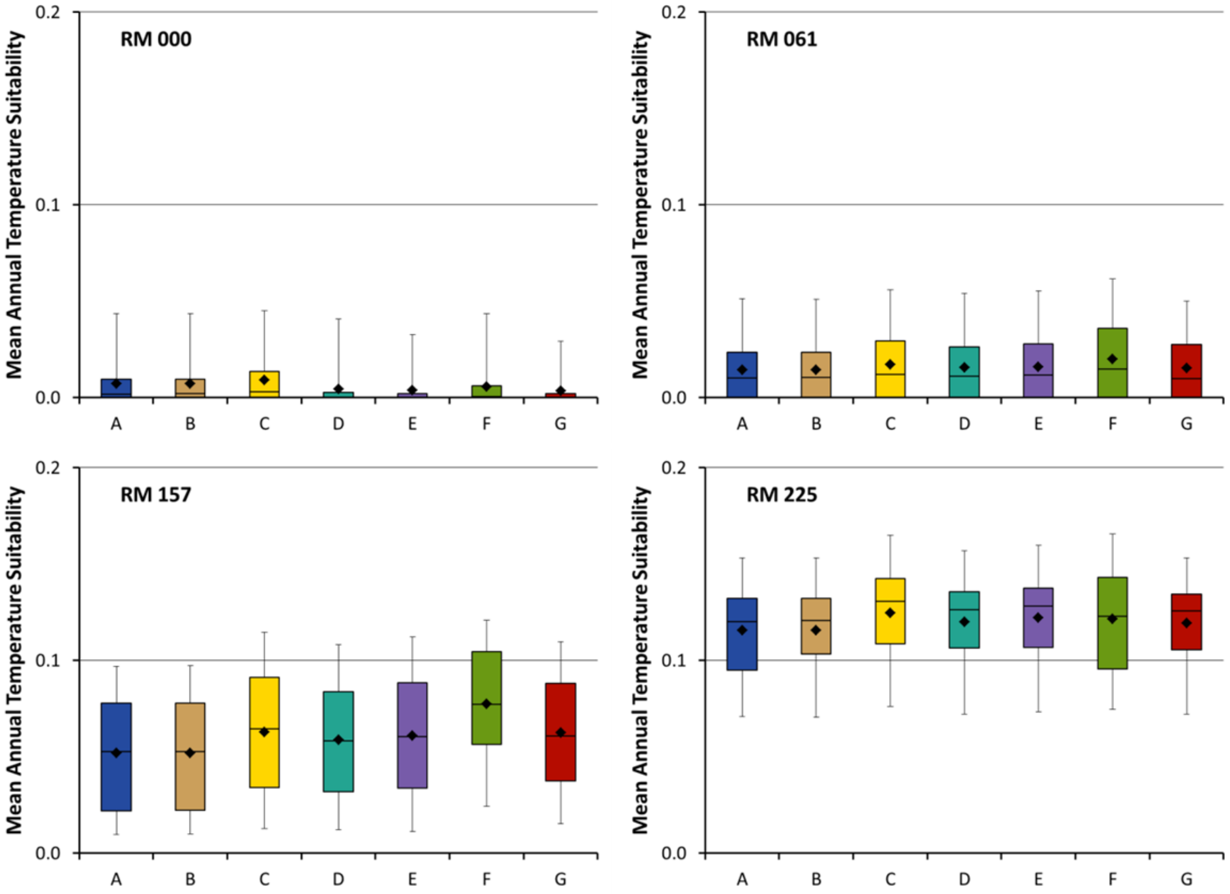

FIGURE 4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish (smallmouth bass, green sunfish, channel catfish, and striped bass) under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.5.2.3 Native Fish

Humpback Chub

Relatively little spawning and juvenile rearing of humpback chub occurs in the mainstem of the Colorado River, primarily because of relatively cold water (Andersen 2009). This species requires a minimum temperature of 16°C to reproduce, but mainstem water temperatures typically have ranged from 7 to 12°C during the spawning period (Andersen 2009). Drought-induced lower reservoir levels have resulted in warmer releases and mainstem water temperatures since 2003; temperatures have consistently exceeded 12°C in the summer and fall, and may have played a role in the recent observed increase in the humpback chub population (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014).

Although survival of larval and juvenile humpback chub in the mainstem was very rare prior to 2000 (Clarkson and Childs 2000), mainstem conditions since the mid-2000s appear to have been suitable for juvenile growth, survival, and recruitment (Yackulic et al. 2014). Warmer water has been shown in the laboratory to increase hatching success, larval survival, and larval and juvenile growth; to improve swimming ability; and to reduce predation vulnerability from rainbow trout (Ward 2011; Ward and Morton-Starner 2015). Yackulic et al. (2014) speculated that when water temperatures are favorable, growth and survival of juveniles in the mainstem will be greater, resulting in increased mainstem recruitment and a larger adult population.

Under all alternatives, main channel water temperature at humpback chub aggregation areas was estimated to continue to be relatively low for spawning and egg incubation during spring and early summer at most locations downstream of Glen Canyon Dam (Figure 4.5-6). Modeled mean annual main channel temperature suitability for humpback chub at RM 61 (the Little Colorado River confluence) was slightly higher under Alternative F than under the other alternatives (Figure 4.5-6), because the low summer and fall flows of this alternative resulted in warmer water during these months. Because the water warms as it travels downstream from the dam, temperature suitability improves with increasing distance. At RM 213, mean annual temperature suitability was highest under Alternatives A, B, D, and G, and slightly lower under Alternatives C and E (Figure 4.5-6), although overall differences were small among these alternatives. Modeled temperature suitability at RM 213 was lowest under Alternative F (Figure 4.5-6), reflecting the higher, colder flows expected to occur under this alternative during spawning and egg incubation periods (April through June). Based on these results, the combined suitability of mainstem temperatures for spawning, egg incubation, and growth by humpback chub in the downstream-most aggregation sites is anticipated to be negatively affected under Alternative F; however, for the other alternatives, this would remain similar to the low historic levels, as represented by the suitability of Alternative A (the No Action Alternative). It should be noted that, historically, there have been years where the magnitude and timing of mainstem water temperatures have likely coincided to allow spawning and egg incubation to occur in some of the downstream aggregation areas; however, the overall average suitability, as measured by the models used in this analysis, has likely been low.

Based on temperature-dependent growth relationships developed by Robinson and Childs (2001), mean total lengths of YOY humpback chub at the end of their first growing season would differ little among the alternatives, although values under Alternative F could be slightly higher than under other alternatives (Figure 4.5-7). In addition, YOY humpback chub that rear in the main channel would be expected to reach a greater mean total length (approximately two times longer) by the end of the first calendar year at the Pumpkin Spring aggregation location (RM 213) than at the confluence with the Little Colorado River (RM 61) due to warming of the water as it travels downstream from Glen Canyon Dam (Figure 4.5-7).

HFEs, TMFs, and low summer flows would be included in many of the alternatives, but none of these flow actions would result in more than a 1 or 2°C change in average monthly water release temperatures or downstream water temperatures during periods of the year considered most important for spawning and egg incubation (i.e., April through June) at any of the humpback chub aggregation locations.

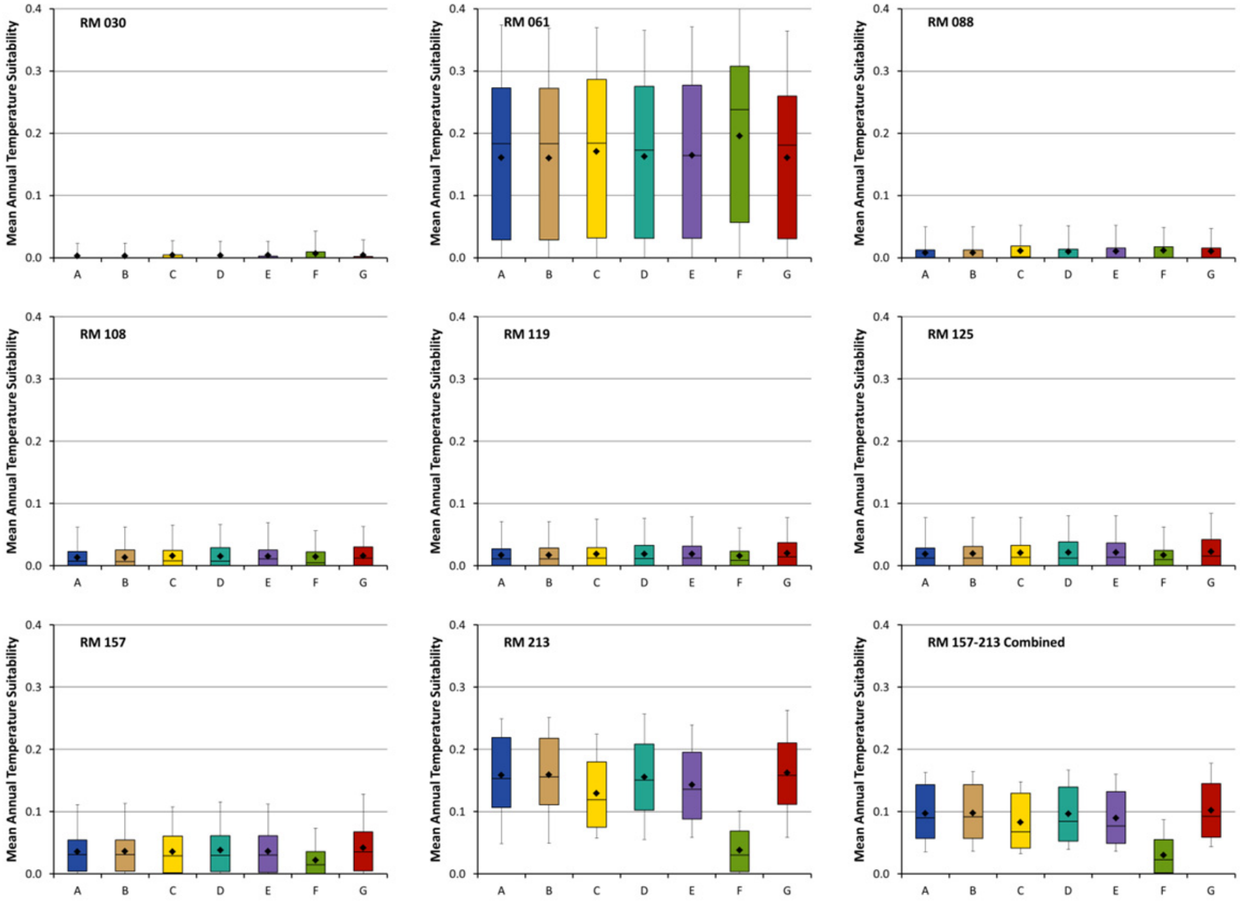

FIGURE 4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under LTEMP Alternatives at Reported Aggregation Locations and Combined Temperature Suitability for RM 157 and RM 213 Locations (Temperature suitability is higher at RM 61 because spawning, incubation, and rearing values are based on temperatures in the relatively warm Little Colorado River where these life history elements occur. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Adult humpback chub numbers were modeled for each alternative under a range of hydrologic and sediment conditions. Overall, the minimum population sizes observed among the alternatives during the 20-year simulations ranged from 1,441 to 13,478 humpback chub (Figure 4.5-8). The lowest modeled minimum adult population size (1,441 fish) was observed under Alternative F, although the lowest minimum adult population values were relatively similar among all alternatives (1,441 to 1,912 adult fish). Similarly, the highest minimum numbers of adult humpback chub were similar among all the alternatives, with values exceeding 13,100 adult fish. The modeled average minimum population size ranged from 4,450 fish under Alternative F to 5,392 fish under Alternative B (Figure 4.5-8). The average minimum number of adult humpback chub was highest for Alternatives B, D, and E, slightly lower under Alternatives A and C, and lowest under Alternatives F and G (Figure 4.5-8). These results indicate that although there are small differences among the alternatives with regard to the

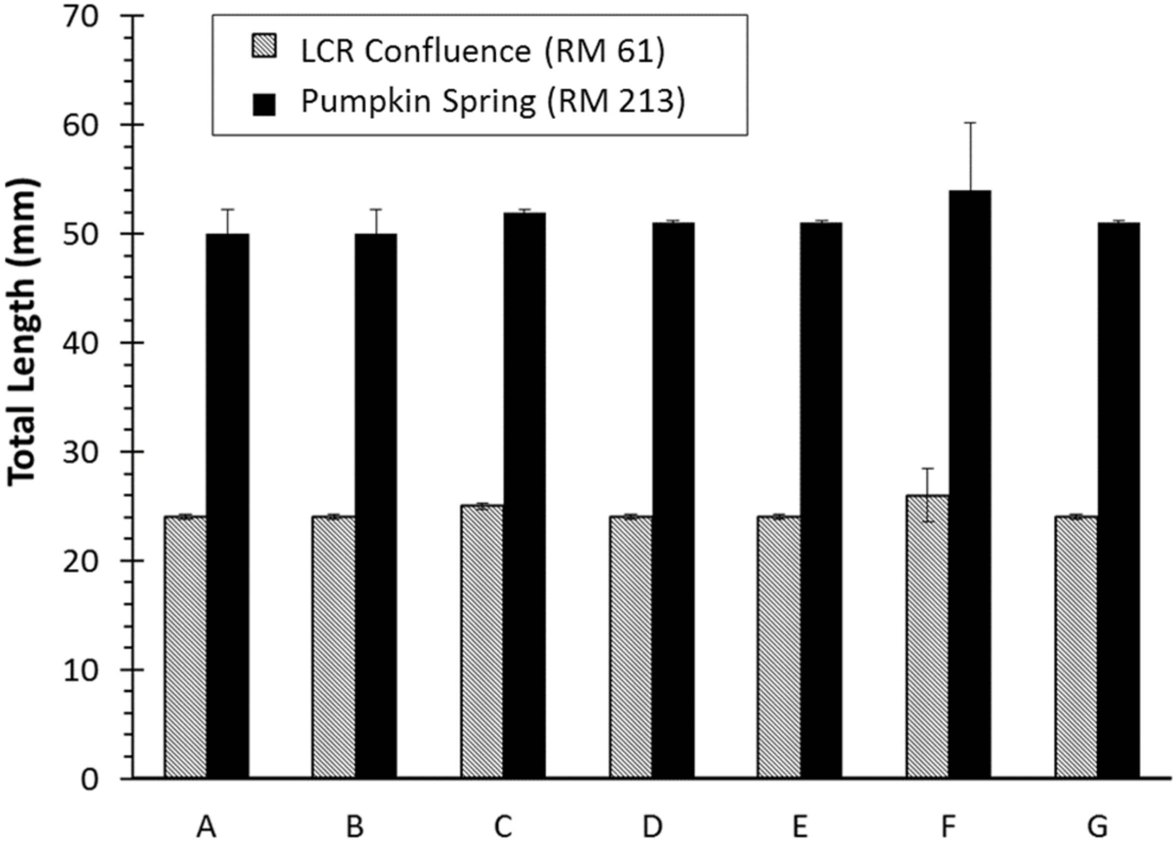

FIGURE 4.5-7 Mean (±1 standard error [SE]) Modeled Total Length Attained by December 31 for YOY Humpback Chub Based on Predicted Mainstem Water Temperatures at the Little Colorado River Confluence (RM 61) and at Pumpkin Spring (RM 213) under Each Alternative (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

predicted minimum number of adult humpback chub in the Little Colorado River aggregation, all alternatives would maintain the population above at least 1,000 adults throughout the 20-year LTEMP period. The model does not consider the potential effects of alternatives on food base productivity, and thus may underestimate or overestimate the impacts on minimum humpback chub numbers. Predicted increases in humpback chub numbers could be offset by decreases in food base productivity under alternatives with greater fluctuations, such as Alternatives B and E. Predicted increases in humpback chub numbers under Alternative D could be bolstered by improvements in food base productivity resulting from more even monthly volumes and moderate fluctuations.

The differences in estimated minimum numbers of adult humpback chub among the alternatives were related, in part, to the estimated levels of recruitment of rainbow trout in the Glen Canyon reach, and to the resulting emigration of rainbow trout to the Little Colorado River reach where survival of YOY and juvenile humpback chub and subsequent recruitment of adult humpback chub could be affected by increased competition and predation from these trout

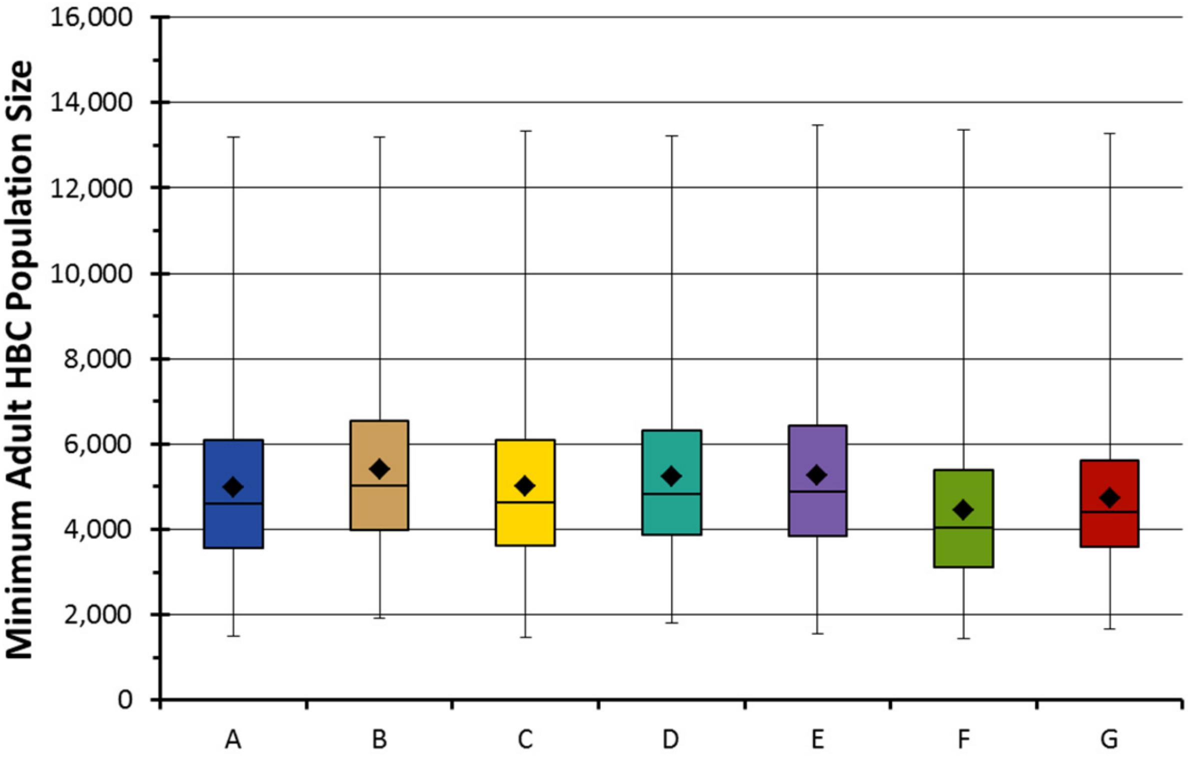

FIGURE 4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year LTEMP Period under LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

(e.g., Yard et al. 2011). As previously discussed, observations indicate that both rainbow trout recruitment and emigration would increase with implementation of HFEs and with reduced levels of daily fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012). Alternatives with the most HFEs over a 20-year period are Alternatives C (mean of 21 HFEs), D (mean of 21 HFEs), F (mean of 19 sediment-triggered HFEs and an additional 19 non-triggered 45,000 cfs flow spikes in early May), and G (mean of 24 HFEs). Alternatives F and G additionally have no within-day fluctuations in flows and, consequently, are expected to have the lowest minimum population levels for adult humpback chub. Although water temperatures will alter the effect of trout on humpback chub survival and recruitment in some years (e.g., periods when lower reservoir elevations result in warmer releases), the overall differences in temperature regimes among the alternatives over the 20-year periods evaluated are expected to be relatively small. Based on results of laboratory studies on the effects of temperature on predation of humpback chub by trout (Ward and Morton-Starner 2015), the temperature-mediated differences in predation rates by trout among the various alternatives would be negligible.

TMFs are designed to cause mortality in YOY rainbow trout by inundating low-angle, near shore habitats for several days, and then quickly reducing dam discharge which would strand YOY fish. Although TMFs target the Glen Canyon area, where most rainbow trout production occurs, stage changes from the TMFs also will occur downstream in Marble and Grand Canyons (see discussion in Section 3.2.1.2). Thus, stranding of native fish further downstream could also occur, including the stranding of endangered humpback chub and razorback sucker.

Aquatic habitats along the river margin, including backwaters, and other slack water habitats may be important for juvenile native fish rearing because water temperatures may be warmer than in the main channel, and due to the presence of cover such as inundated roots, and overhanging and rooted vegetation. In monthly sampling of randomly selected larval fish habitats from Lava Falls (approximately RM 180) to Lake Mead between March and September, 2014, Albrecht et al. (2014) found that small-bodied YOY native fish catch rates in slack water and channel margins were highest in June through August. Endangered YOY humpback chub were first captured in May and were captured in all months until September. Larval razorback sucker have been captured in channel margin habitats from April to August (Albrecht et al. 2014; Kegerries et al. 2015). In Marble Canyon near the Little Colorado River inflow, Dodrill et al. (2015) showed that juvenile native fish, including humpback chub, can occur in high densities in backwaters and other channel margin habitats.

The extent of mortality due to stranding of native fish, including endangered species, in a given year in Marble and Grand Canyons as a result of TMFs is unknown, and may depend on the quantity of channel margin habitats and their sensitivity to flow changes, the distribution and abundance of juvenile fish in sensitive habitats, the timing and number of TMFs, and the degree of attenuation of flows downstream. TMFs could be implemented from May through August, which would overlap with the presence of larval fish for many of the native fish species. Given that razorback sucker spawning was recently documented in the study area in 2014 and 2015 (Albrecht et al. 2014; Kegerries et al. 2015) and studies are ongoing, potential impacts on the species are particularly difficult to predict. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected, an unknown number of native fish could also suffer mortality as a result of TMFs, downstream in GCNP. Risk to native fish would likely vary by location depending upon the level of stage changes that would be experienced and the steepness of shallow nearshore areas. Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

Low summer flows included under Alternatives C, D, and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitats, potentially benefitting humpback chub. However, providing warmer nearshore habitats also could promote recruitment and survival of nonnative fish species that prey on or compete with humpback chub. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows and offset any benefits to humpback chub. However, effects on nonnative fish and humpback chub would be carefully monitored, and these experiments could be discontinued if adverse impacts on humpback chub were anticipated.

Impacts on Other Native Fish

The distribution and abundance of native fish (other than humpback chub) could be affected by alternative-specific differences in temperature regimes, food production, sediment dynamics, and flow patterns. For the endangered razorback sucker (*Xyrauchen texanus*), suitable water temperatures for spawning, egg incubation, and growth range from 14 to 25°C (FWS 2002a), with estimated optimal temperatures of 18°C for spawning, 19°C for egg incubation, and 20°C for growth (Valdez and Speas 2007). Hatching success is temperature dependent, with complete mortality occurring at temperatures less than 10°C (AZGFD 2002a). Young razorback suckers require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs (FWS 2002a). During 2014 and 2015, razorback sucker larvae were found in the Colorado River as far upstream as RM 173 (upstream of Lava Falls), which is the farthest upstream razorback sucker spawning has been documented in the Grand Canyon (Albrecht et al. 2014; Kegerries et al. 2015). Additional larval sampling in the lower Grand Canyon found razorback sucker larvae to be distributed throughout most shoreline habitats from Lava Falls to Pearce Ferry from May to July and life stages from larvae through subadults are likely occur within these sections of the river. The highest density of razorback sucker larvae were found in isolated pools in 2014 and 2015, although such habitats composed only about 2% of all habitat sampled (Albrecht et al. 2014; Kegerries et al. 2015) (as noted above, TMFs have the potential to strand razorback sucker and other native sucker larvae as well as rainbow trout). Given the need for warm, productive floodplain or backwater habitats for rearing of larval and juvenile native fishes, and the lack or low abundance of nonnative fish found in recent backwater sampling (Albrecht et al. 2014; Kegerries et al. 2015), reduced fluctuations, lower flows, or low summer flows may benefit razorback sucker by providing warm and persistent backwater habitats. Low summer flows would likely increase warming and overall stability in these nearshore habitats, potentially benefitting razorback sucker in the Grand Canyon. Because HFEs and low summer flows affect the creation and maintenance of backwater habitats used by larval or juvenile razorback sucker, these flow actions could benefit razorback sucker. Low summer flows potentially create or maintain warm backwater habitat beneficial to razorback sucker rearing, and spring HFEs may create backwater habitat during a time that may coincide with spawning and emergence of larval razorback sucker.

Two additional species of native suckers—bluehead sucker (*Catostomus discobolus*) and flannelmouth sucker (*C. latipinnis*)—occur in the Colorado River between Glen Canyon Dam and the headwaters of Lake Mead. Bluehead sucker spawning occurs at water temperatures >16°C (AZGFD 2003a; NPS and GCNP 2013); spawning is primarily limited to tributaries. In the Grand Canyon, flannelmouth suckers spawn at water temperatures ranging from 6 to 18°C in or near a limited number of tributaries, especially the Paria and Little Colorado Rivers (AZGFD 2001b; Weiss et al. 1998; Douglas and Douglas 2000), and Bright Angel Creek (Weiss et al. 1998). Flannelmouth sucker larvae, juveniles, and adults were encountered in the mainstem Colorado River of the lower Grand Canyon during surveys conducted in 2014 (Albrecht et al. 2014). Spawning may be timed to take advantage of warm, ponded conditions at tributary mouths that occur during high flows in the mainstem Colorado River (Bezzerides and Bestgen 2002). In the tailwaters below Glen Canyon Dam, mainstem water temperatures (8 to 12°C) are either at the lower end of or below those needed for spawning and recruitment of flannelmouth suckers. Even though some warming does occur downstream, the relatively cold water in summer is thought to limit survival of YOY fish, recruitment, and condition of this species in the main channel (Thieme et al. 2001; Rees et al. 2005; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam of both species was low in the 1990s and then increased after 2000; the largest recruitment estimates coincided with brood years 2003 and 2004, when there was an increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012). From 2008 through 2014, the numbers of flannelmouth suckers captured in electrofishing surveys was greater in mainstem sample locations downstream of RM 109 (Albrecht et al. 2014), perhaps giving an indication of the point at which water temperatures became more suitable for recruitment. The speckled dace (*Rhinichthys osculus*) is native to all major western drainages from the Columbia and Colorado Rivers south to Mexico (AZGFD 2002c). Within the Grand Canyon, this species occurs within the mainstem Colorado River and its tributaries, including the Little Colorado River (Robinson et al. 1995; Ward and Persons 2006; Makinster et al. 2010). Long-term fish monitoring of the Colorado River below Glen Canyon Dam since 2000 shows the speckled dace to be the third most common fish species (and most common native species) in the river between Glen Canyon Dam and the Lake Mead inflow; it was captured most commonly in western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010). The speckled dace spawns during the spring to late summer periods (AZGFD 2002c) at temperatures >17°C (NRC 1991).

To examine the potential of each alternative to produce thermal conditions that could improve reproduction, recruitment, and growth of native fish in main channel habitats, temperature suitability was modeled at various locations downstream from Glen Canyon Dam for the four native fish species other than humpback chub that occur in the river between Glen Canyon Dam and Lake Mead (bluehead sucker, flannelmouth sucker, razorback sucker, and speckled dace). In general, the estimated temperature suitability for these species did not differ greatly among the alternatives, was comparable to suitability under current operations (Alternative A), and was low for all four species at most locations (Figure 4.5-9). At RM 225 (Diamond Creek), the mean modeled temperature suitability for native fish was highest under Alternative D and lowest under Alternative F; the mean temperature suitability levels for Alternatives A, B, C, E, and G were similar to each other at RM 225 (Figure 4.5-9). Inclusion of flow actions such as HFEs, TMFs, and low summer flows had only minor influences on modeled monthly mainstem water temperatures during periods of the year considered most important for spawning and egg incubation by native fish. As a consequence, these flow actions would have minor effects on temperature suitability for native fish and would not alter the relative suitability among alternatives.

Low summer flows included under Alternatives C, D and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitat, potentially benefitting razorback suckers and other native fish. However, providing warmer nearshore habitats could also promote recruitment and survival of nonnative fish species that prey on or compete with native fish species. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low

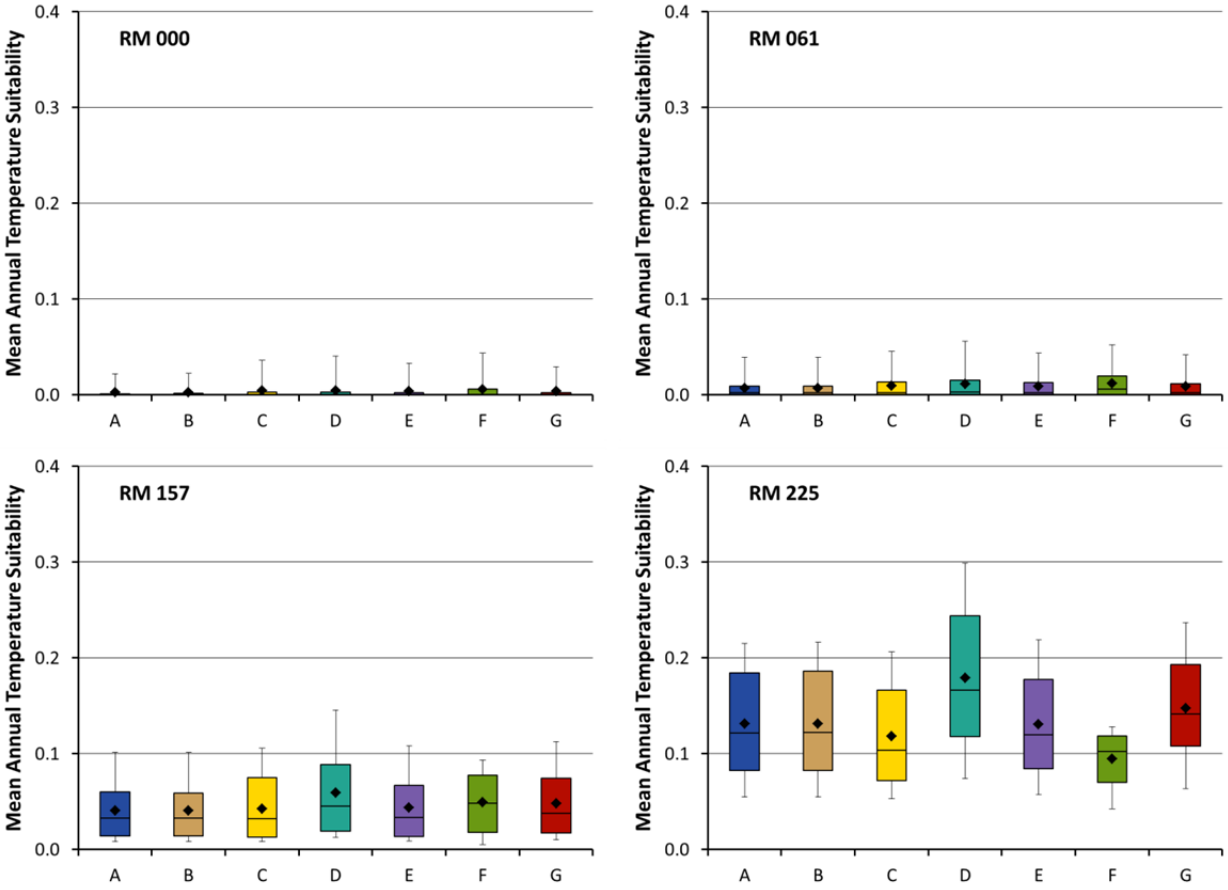

FIGURE 4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish (bluehead sucker, flannelmouth sucker, razorback sucker, and speckled dace) under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

summer flows and offset any benefits to razorback suckers and other native fish. However, the effects on nonnative fish, razorback suckers, and other native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

4.5.2.4 Aquatic Parasites

The distribution and potential for infestation of aquatic parasites could be affected by alternative-specific differences in temperature regimes, sediment dynamics, and flow patterns. Of these factors, only the effects of temperature were considered to potentially be large enough to result in impacts on aquatic parasites. Temperature suitability was modeled at various locations downstream from Glen Canyon Dam for the four most important parasite species (Asian tapeworm, anchor worm, trout nematode, and whirling disease). Based on modeling, suitability under all alternatives and all species would generally be very low, would not differ at a biologically significant level among alternatives, and would be comparable to conditions under current operations as represented by Alternative A (No Action Alternative; Figure 4.5-10). As a consequence, the relative distributions of aquatic parasites in the mainstem or the effects of aquatic parasites on survival and growth of native fish or trout would not be expected to change relative to current conditions under any of the alternatives.

Low summer flows included under Alternatives C, D and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitat, potentially increasing the occurrence of aquatic parasites. However, the effects on trout and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated. Under current conditions, population-level effects of parasites on survival and growth of native fish or trout have not been observed.

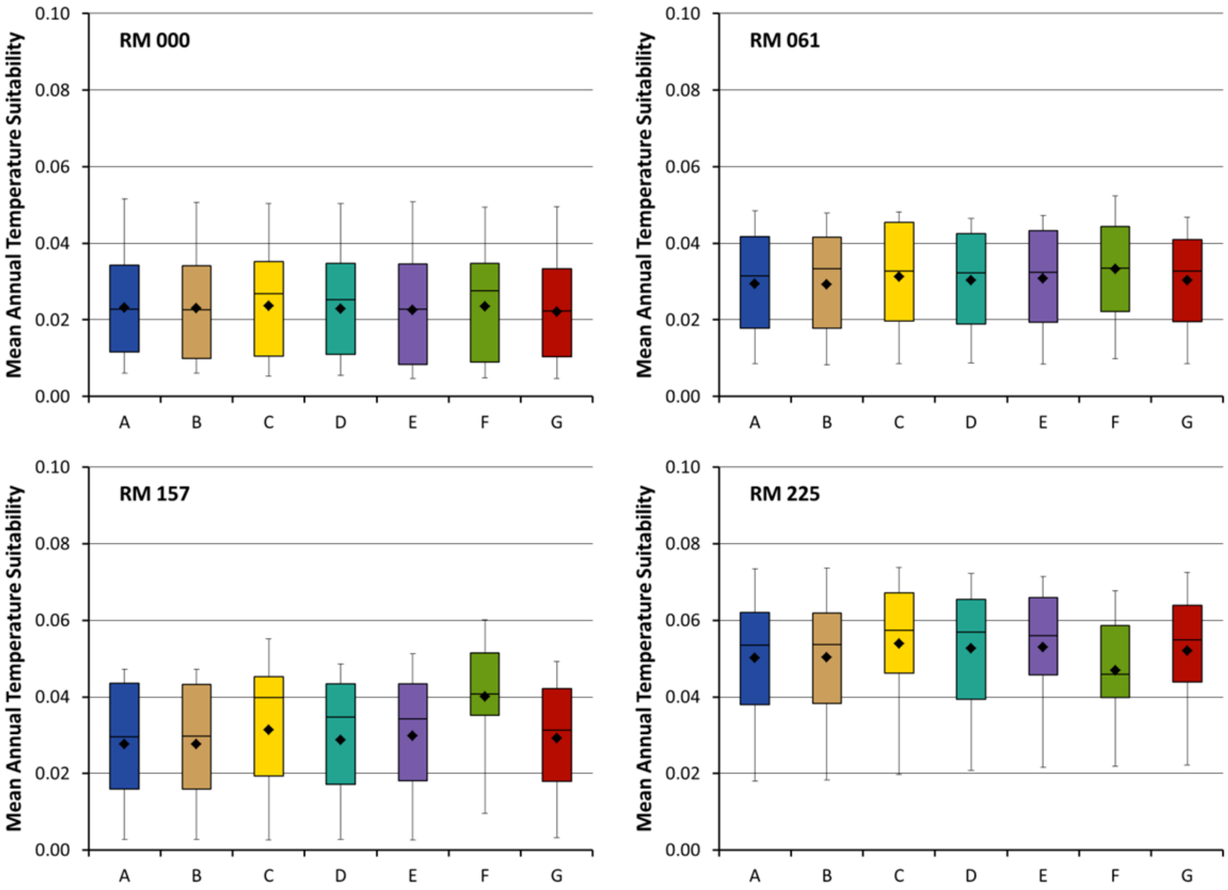

FIGURE 4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives for Aquatic Fish Parasites (Asian tapeworm, anchor worm, trout nematode, and whirling disease) at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.5.3 Alternative-Specific Impacts on Aquatic Resources

This section describes alternative-specific impacts on aquatic resources, and focuses on assessment results. More detailed descriptions of the basis of impacts and supporting literature citations for these impacts are presented in Section 4.5.2. As described above, none of the alternatives would be expected to noticeably alter temperature suitability for aquatic parasites, and the relative distributions of aquatic parasites and the effects of aquatic parasites on survival and growth of native fish or trout would not be expected to change relative to current conditions under any of the alternatives. For this reason, this topic is not discussed below.

As described in the following sections, although differences among alternatives on their effects on humpback chub are expected to be small, Alternatives B, D, and E are expected to result in the highest average minimum number of adult humpback chub during the 20-year LTEMP period, compared to Alternative A, indicating that these alternatives could improve the potential for sustaining this species in the Grand Canyon ecosystem. Alternatives F and G are expected to result in decreases in the average minimum number of adult humpback chub compared to Alternative A. Under Alternatives B and D, temperature suitability and growth for humpback chub are expected to remain similar to those under Alternative A.

4.5.3.1 Alternative A (No Action Alternative)

Impacts of Alternative A on Aquatic Food Base

Alternative A, the No Action Alternative, would continue the implementation of MLFF and other flow and non-flow actions currently in place and, as a consequence, existing conditions and trends in the composition, abundance, and distribution of the aquatic food base is expected to persist over the LTEMP period. That being said, any significant hydrologic changes over the period or inadvertent introductions of nonnative species could result in unanticipated changes. The future impact of the recent introduction of quagga mussels on the aquatic food base is uncertain.

Dam operations under MLFF have led to increases in the standing mass of food base organisms (i.e., algae and invertebrates) due to steadier flows and greater minimum releases relative to operations prior to 1991. By restricting daily fluctuations in discharge to <8,000 cfs and limiting minimum discharge to 5,000 cfs, the MLFF regime has reduced the size of the varial zone and increased the amount of river bottom that is permanently submerged. Both of these conditions potentially increase the productivity and standing mass of important components of the aquatic food base. Fluctuating flows displace benthic macroinvertebrates into the drift, but they usually recover quickly from such disturbances. The effect of freezing during winter will reduce benthic productivity to the minimum stage level (Shannon et al. 1994; Blinn et al. 1995). The ramping rates for Alternative A would cause a minor increase in drift over the course of a fluctuation, particularly during up-ramping.

For Alternative A, an average of 5.5 HFEs would occur over the 20-year LTEMP period, with a maximum of 14 HFEs not extending past 2020; see Table 4.3-1). Impacts on the aquatic food base from a spring or fall HFE under Alternative A would be similar to those discussed in Section 4.5.2.1 (e.g., benthic scouring, particularly for HFEs of 41,000 cfs or more, and a shift to invertebrate species more prone to drift such as midges and blackflies). Drifting blackflies and midges are important contributors to the diet of trout. HFEs under Alternative A would only occur through 2020. Therefore, the number of HFEs would be less than for the other alternatives (Section 4.2). The cessation of HFEs after 2020 may result in a shift back to a food base community not dominated by midges and blackflies (Reclamation 2011a).

As mentioned in Section 4.5.1.2, trout removal, as would occur under Alternative A, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources.

Water temperatures, and their resultant influences on species composition, diversity, and production of the aquatic food base, under the base operations of Alternative A would be similar to current temperatures in the Colorado River downstream of Glen Canyon Dam.

Impacts of Alternative A on Nonnative Fish

Under Alternative A, no change from current conditions is anticipated. Trout would continue to be supported in the Glen Canyon, Marble Canyon, and Little Colorado River reaches. Warmwater nonnative species would continue to be largely restricted to the lower portions of the river nearer to the headwaters of Lake Mead except in areas where warmer inflows from tributaries provide appropriate temperature regimes, or are sources of nonnative fish, from outside GCNP.

Within-day flow fluctuations (between 5,000 and 8,000 cfs) would continue to affect the stability of spawning habitats for rainbow trout and nearshore habitats for other nonnative fish (Reclamation 1995; Korman et al. 2005; Korman, Kaplinski et al. 2011; Korman and Melis 2011), and would result in trout redd exposure and stranding levels similar to those currently occurring. Implementation of spring and fall HFEs could result in increased recruitment of rainbow trout in the Glen Canyon reach, followed by increased emigration of trout to the Little Colorado River reach (Wright and Kennedy 2011; Korman et al. 2012). These HFEs would not be implemented after 2020 under Alternative A.

Because of the relatively small number of HFEs that would be implemented under this alternative, opportunities for any such increases in trout abundance under Alternative A would be the lowest among all alternatives. TMFs are not included as an explicit element of Alternative A. Mechanical removal of trout at the Little Colorado River confluence, as described in

Reclamation (2011a), would be allowed only up through 2020.[10] Other alternatives would allow these management actions to be implemented throughout the entire LTEMP period if tests are deemed successful (e.g., Alternatives B, C, D, E, and G). The modeled average rainbow trout population size in the Glen Canyon reach during the 20-year LTEMP period was about 95,000 age-1 and older fish, with an average annual emigration from the Glen Canyon reach to the Marble Canyon reach of about 37,000 fish. The modeled number of large trout (>16 in. total length) averaged about 770 fish under Alternative A.

Impacts of Alternative A on Native Fish

Under Alternative A, within-day flow fluctuations (5,000 to 8,000 cfs), and ramp rates (4,000 cfs/hr up ramp and 1,500 cfs/hr down ramp), would continue to affect the stability and quality of nearshore habitats used by native fish, and would not result in a change in current conditions. Mainstem temperature suitability for humpback chub and other native fish would continue to be relatively low in most years.

Mainstem water temperatures are expected to continue restricting successful reproduction of humpback chub and other native fish to areas warmed by inflows from springs, to tributaries, or to nearshore locations that are far enough downstream for substantial warming to occur (e.g., RM 157 or farther downstream). Under Alternative A, successful spawning, larval survival and growth, and juvenile growth of humpback chub would continue to occur mostly in the Little Colorado River, with possible spawning occurring in Havasu Creek (NPS 2013g) and additional nursery and rearing habitats being used between RM 180 and RM 280 (Albrecht et al. 2014). Successful spawning of razorback sucker has recently been documented as far upstream as Lava Falls in the lower Grand Canyon under current operations (Albrecht et al. 2014; Kegerries et al. 2015) and would be expected to continue to occur under Alternative A, at least in years when temperature regimes are suitable.

The abundance, distribution, reproduction, and growth of native fishes, including humpback chub, are not expected to change appreciably from current conditions as a result of implementing Alternative A. The estimated average minimum number of adult humpback chub under Alternative A is about 5,000 adult fish over the 20-year LTEMP period, which is similar to the estimated minimum adult humpback chub numbers that have occurred during the period from 1989 through 2012 (see Section 3.5.3.1). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period is about 1,500. Under Alternative A, it is estimated that YOY humpback chub would achieve a total length of about 24 mm by the end of their first year at RM 61, and about 50 mm at RM 213 if rearing occurred in main channel habitats; fish of these sizes are unlikely to survive the winter in the mainstem. HFEs that could be implemented under this alternative (an average of 5.5 and a maximum of 14 over a 20-year period) would be similar to existing frequencies, so levels of recruitment of rainbow trout in the Glen Canyon reach of the river and numbers of rainbow trout emigrating to downstream reaches,

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[10] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

where they may compete with and prey on humpback chub and other native species, would be expected to be unchanged.

Summary of Alternative A Impacts

Under Alternative A, existing conditions and trends in the composition, abundance, and distribution of the aquatic food base is expected to persist over the LTEMP period (e.g., increases in the standing mass of food base organisms). The cessation of HFEs after 2020 may shift to a food base community not dominated by midges and blackflies. Drifting midges and blackflies are important contributors to the diet of trout. Water temperatures, and their resultant influences on species composition, diversity, and production of the aquatic food base under the base operations of Alternative A, would be similar to current temperatures in the Colorado River downstream of Glen Canyon Dam.

Under Alternative A, there would be no change from current conditions for nonnative and native fish. HFEs (especially spring HFEs) could increase recruitment of rainbow trout in the Glen Canyon reach followed by increased emigration to the Little Colorado reach. However, HFEs would not be implemented after 2020. The modeled average rainbow trout population size during the 20-year LTEMP period was about 95,000 age-1 and older fish, with an average annual emigration from the Glen Canyon reach to the Marble Canyon reach of about 37,000 fish. The modeled number of large trout (>16 in. total length) averaged about 770 fish under Alternative A. Under Alternative A, the estimated average and absolute minimum number of adult humpback chub under Alternative A is about 5,000 and 1,500 adult fish over the 20-year LTEMP period. It is anticipated that spawning and habitat conditions for razorback sucker would remain similar to current conditions.

4.5.3.2 Alternative B

Impacts of Alternative B on Aquatic Food Base

UnderAlternative B, monthly release volumes would be similar to those under Alternative A, thus providing comparable areas for benthic production. However, the greater allowable daily flow fluctuations under Alternative B would create a wider varial zone and therefore lower benthic production than under Alternative A. More rapid down-ramp rates under Alternative B may result in greater instability and reduced quality of backwater and varial zone habitats. Thus, drift rates and stranding within the varial zone may be somewhat higher for Alternative B compared to Alternative A.

Fluctuating flows (>10,000 cfs/day) can fragment *Cladophora* from its basal attachment and increase its occurrence in the drift. Consuming drifting *Cladophora* (with its attached epiphytes and any invertebrates) allows rainbow trout to expend less energy in searching for food (Leibfried and Blinn 1987). Daily range in flows >10,000 cfs for base operations only occur during December and January (12,000 cfs) for Alternative B.

Slightly more HFEs would occur during the 20-year LTEMP period under this alternative than under Alternative A (mean of 7.2 vs. 5.5, respectively). Impacts on the aquatic food base from a spring or fall HFE under Alternative B would be similar to those discussed under Alternative A. However, there would not be more than one (spring or fall) HFE every other year. Less frequent HFEs (e.g., less often than annually) may lower the potential for establishing an aquatic food base that is more adaptable to flood conditions (e.g., an increased shift to blackflies and midges). Alternative B would have relatively few HFEs (Table 4.3-1); however, unlike Alternative A, HFEs would be implemented over the entire LTEMP period.

Hydropower improvement flows, tested experimentally under Alternative B up to four times in years with ≤8.23 maf, could decrease primary and secondary production because of scouring, although macroinvertebrate drift may increase in the short term. Rapid down-ramping may increase stranding of organisms in the varial zone, and this could reduce invertebrate productivity.

Mechanical removal of trout near the Little Colorado River could indirectly increase the availability of invertebrates to native fish because of reduced competition for food resources. Under Alternative B, TMFs would be tested and implemented, if tests are successful. TMFs could increase drift rates and slightly decrease primary production.

Water temperatures in the Colorado River under Alternative B would be similar to current temperature conditions because monthly volumes would be identical to those of Alternative A. Therefore, temperature impacts on the aquatic food base would be similar to those for Alternative A.

Impacts of Alternative B on Nonnative Fish

Under Alternative B, trout would continue to be supported in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Under Alternative B, habitat quality and stability may be slightly reduced compared to Alternative A. The higher within-day flow fluctuations (6,000–12,000 cfs), and down-ramp rates (3,000–4,000 cfs/hr) could adversely affect the stability of nearshore main channel habitats. The greater within-day flow fluctuations and faster down-ramp rates could also result in greater levels of exposure of trout redds and stranding of YOY rainbow trout. Stability of nearshore habitats under Alternative B could also be negatively affected by inclusion of testing of hydropower improvement flows, which would include an experimental feature to be employed four times in a 20-year period with wide daily flow fluctuations (up to a 5,000- to 25,000-cfs range) and would allow increased up- and down-ramp rates. Temperature suitability under Alternative B would be similar to that under Alternative A for both coldwater and warmwater nonnative fish.

Although slightly more HFEs would occur during the 20-year LTEMP period under this alternative than under Alternative A (mean of 7.2 vs. 5.5, respectively), the estimated abundance and emigration of rainbow trout would be less than under Alternative A (74,000 vs. 95,000 average abundance; 30,000 vs. 37,000 average number of emigrants). These lower abundance and emigration numbers reflect the effect of greater within-day flow fluctuations and ramp rates. The number of large trout (>16 in. total length) was estimated to average about 870 fish, which is more than under Alternative A. Inclusion of hydropower improvement flows would be expected to result in even lower trout abundance and emigration and an increase in the numbers of large trout (see Appendix F).

TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if the tests were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative B, it is anticipated that TMFs would be triggered in 3 out of 20 years, on average. Alternative B also would allow use of triggered mechanical trout removal at the Little Colorado River for the entire 20-year LTEMP period, whereas such removal would cease after 2020 under Alternative A.[11] Modeling indicates that the inclusion of these actions may be able to reduce the abundance of trout in both the Glen Canyon and Little Colorado River reaches and could benefit the humpback chub population in the vicinity of the Little Colorado River throughout the LTEMP period (see Appendix F). The modeled average trout population size in Glen Canyon under Alternative B was substantially lower than under Alternative A (Figure 4.5-2).

Impacts of Alternative B on Native Fish

Under Alternative B, higher within-day flow fluctuations and down-ramp rates could result in greater instability and reduced quality of nearshore habitats as compared to Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9) in the mainstem river, as well as estimated growth of YOY humpback chub (Figure 4.5-7), would differ little from suitability and growth under Alternative A.

Higher within-day fluctuations during most periods of the year, limitations on the allowable frequency of HFEs, and implementation of TMFs would be expected to reduce recruitment of rainbow trout and the potential for rainbow trout emigration to the Little Colorado River reach (RM 61) compared to Alternative A, which is expected to reduce competition with and predation by rainbow trout on native fishes in that reach (Yard et al. 2011). Alternative B also includes mechanical trout removal near RM 61 for the entire 20-year period, whereas such removal would cease after 2020 under Alternative A.

Considering the lower trout recruitment that would result from higher within-day fluctuations, low number of HFEs, and implementation of triggered TMFs, the average modeled minimum number of adult humpback chub (about 5,400 adult fish) is higher under Alternative B than under Alternative A (about 5,000 adult fish). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative B is about 1,900. However, predicted increases in humpback chub numbers could be offset by decreases in food base productivity resulting from higher fluctuations under Alternative B (see discussion of

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[11] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

fluctuations in Section 4.5.2.1 and in Appendix F). While indirect benefits of TMFs on native fish (including razorback sucker) as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

Summary of Alternative B Impacts

Under Alternative B, the area of main benthic food base production would be similar to Alternative A. HFEs conducted less often than annually may lower the potential to establish a food base adaptable to flood conditions (i.e., one dominated by midges and blackflies). Hydropower improvement flows could decrease benthic primary and secondary food base production, although macroinvertebrate drift may increase in the short term. Temperature impacts on the aquatic food base under Alternative B would be similar to those under Alternative A.

Under Alternative B, habitat quality and stability and temperature suitability for both nonnative and native fish (including humpback chub and razorback sucker) may be slightly reduced compared to Alternative A. The estimated abundance and emigration of rainbow trout under Alternative B would be less than under Alternative A (74,000 vs. 95,000 average abundance; 30,000 vs. 37,000 average number of emigrants). The number of large trout (>16 in. total length) was estimated to average about 870 fish, which is more than the 770 fish estimated under Alternative A. Estimated growth of YOY humpback chub under Alternative B would be similar to Alternative A. The average modeled minimum number of adult humpback chub over the LTEMP period (about 5,400 adult fish) is slightly higher under Alternative B than under Alternative A (about 5,000 adult fish). The estimated absolute minimum number of adult humpback chub under Alternative B is about 1,900 compared to 1,500 for Alternative A.

4.5.3.3 Alternative C

Impacts of Alternative C on Aquatic Food Base

Compared to Alternative A, Alternative C has higher monthly release volumes (and thus higher benthic biomass) from December through June, and lower volumes (and thus lower benthic biomass) from August through November. The daily range in flows would be lower under Alternative C compared to Alternative A. Therefore, benthic productivity may be somewhat increased particularly in the Glen Canyon reach because less of the benthic substrate would be exposed during fluctuation cycles. Increased benthic productivity would result in long-term increases in benthic drift (Kennedy, Yackulic et al. 2014).

Impacts on the aquatic food base from a spring or fall HFE under Alternative C would be similar to those discussed under Alternative A. Unlike Alternative A, HFEs would be implemented for the entire LTEMP period, with an average of 21.3 HFEs (maximum 40 HFEs) (Table 4.3-1). The more frequent HFEs are expected to favor blackfly and midge production. Proactive spring HFEs with maximum possible 24-hr release up to 45,000 cfs may be implemented under Alternative C in equalization years (years with annual volumes ≥10 maf) if no other spring HFE occurs in the same water year. Although a proactive spring HFE may scour the benthic community, particularly in the Glen Canyon reach, it would also increase the aquatic food base (e.g., blackflies and midges) available to drift-feeding fishes in the short term and may help control New Zealand mudsnail populations (Rosi-Marshall et al. 2010; Kennedy et al. 2013).

Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. Fall HFEs longer than 96 hr (i.e., maximum of 137 hr) could be implemented under Alternative C. The HFE volume would be limited to that of a 45,000 cfs, 96-hr flow. Thus, these extended-duration HFEs would be of lower magnitude and would produce less benthic scouring, assuming less shoreline sediment would be affected by flows less than 45,000 cfs. HFEs longer than 96 hr may help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance, although abundance in the 250-km stretch of river above Lake Mead tends to be more than an order of magnitude less than in the 110-km stretch below Glen Canyon Dam (Shannon, Benenati et al. 2003).

Steady flows would occur just prior to and after spring or fall HFEs under Alternative C. These flows could result in several months of maximized benthic production in the mainstem and possible maintenance and development of planktonic and benthic production in shoreline areas, especially backwaters. Benthic productivity in the mainstem should also increase under steady flows.

Tests and implementation of low summer flows would be conducted under Alternative C if conditions warrant it. Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative C, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative C, TMFs would be tested and implemented, if tests are successful. TMFs could temporarily increase drift rates and slightly decrease primary production.

The slightly warmer mean monthly water temperatures under Alternative C at RM 225 may slightly increase benthic production compared to Alternative A as modeled temperatures would be 18.1 and 18.2°C (64.6 and 64.8°F) for August and September, respectively, compared to 17.2 and 17.4°C (63 and 63.3°F). In addition to favoring adnate diatoms over stalked diatoms, these slightly warmer temperatures would tend to favor *Oscillatoria* over *Cladophora*. Overall, these changes would be considered detrimental to the aquatic food base (Section 4.5.2.1).

Otherwise, temperature impacts on the aquatic food base would be similar to those described for Alternative A (Section 4.5.3.1).

Impacts of Alternative C on Nonnative Fish

Under Alternative C, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish may be higher because of smaller within-day flow fluctuations. However, stranding of YOY rainbow trout may be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability under Alternative C was estimated to be similar that under Alternative A for trout at all locations (Figure 4.5-4), but could slightly improve conditions for warmwater nonnative fish at the locations farthest downstream compared to Alternative A (Figure 4.5-5).

Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. The greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, together with reduced fluctuations, could result in higher rainbow trout recruitment and emigration rates (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative C, it is anticipated that TMFs would be triggered in 6 out of 20 years, on average.

Alternative C also would allow use of triggered mechanical trout removal at the Little Colorado River for the entire 20-year LTEMP period, whereas such removal would cease after 2020 under Alternative A.[12] Modeling indicates that the inclusion of TMFs and mechanical removal may be able to reduce the abundance of trout in both the Glen Canyon and Little Colorado River reaches and could benefit the humpback chub population in the vicinity of the Little Colorado River throughout the LTEMP period (see Appendix F). This alternative has the highest estimated number of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about 44,000 fish), and the fewest large rainbow trout (about 750 fish) relative to all of the other non-steady flow alternatives, even though implementation of TMFs is included as an element of the alternative.

Low summer flows would be included under Alternative C as an experiment during the entire LTEMP period if triggered by low summer water temperatures and low humpback chub numbers. Providing warmer nearshore habitats could promote recruitment and survival of trout and warmwater nonnative fish that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially

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[12] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of the Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of nonnative fish by warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

Impacts of Alternative C on Native Fish

The quantity, quality, and stability of nearshore habitats would be affected less under Alternative C than under Alternative A. Within-day flow fluctuations would be scaled according to monthly volumes (3,500 to 6,000 cfs during average hydrologic conditions) and would be less under this alternative than under Alternative A. However, improvements to habitat stability that may result from reduced fluctuations may be offset, in part, by the higher down-ramp rates (2,500 cfs/hr). Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ little from suitability and growth predicted for Alternative A.

The relatively high number of HFEs under Alternative C would be expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach, with potential adverse effects on humpback chub. The potential for competition with and predation on humpback chub could be offset by mechanical removal of trout in the Little Colorado River reach (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. The estimated average minimum number of adult humpback chub under Alternative C would be similar to that under Alternative A (about 5,000 adult fish) and slightly less than under Alternatives B, D, and E. The estimated average minimum number of adult humpback chub under Alternative C would be greater than under Alternatives F and G. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative C is about 1,500, the same as Alternative A. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

Low summer flows would be included under Alternative C as an experiment during the entire LTEMP period if triggered by low summer water temperatures and low humpback chub numbers, and are expected to increase warming and overall stability of nearshore habitats, which would potentially benefit humpback chub, razorback suckers, and other native fish. Providing warmer nearshore habitats could promote recruitment and survival of nonnative fish species, including trout, that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species that could alter suitability for razorback sucker. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of the Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of native fish by warmwater fish parasites. Effects on parasites, nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

Summary of Alternative C Impacts

Under Alternative C, benthic food base productivity may be higher in December through June due to higher flows, but lower from August through November due to lower flows compared to Alternative A. Overall, benthic productivity should be higher under Alternative C than under Alternative A because of reduced fluctuations and a narrower varial zone. The more frequent HFEs compared to Alternative A favor the production of midges and blackflies. Slightly warmer water temperatures for August and September at RM 225 under Alternative D may slightly increase food base production compared to Alternative A, although this could be offset by change in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

Under Alternative C, habitat quality and stability for nonnative and native fish (including humpback chub and razorback sucker) may be higher than under Alternative A because of smaller within-day flow fluctuations. However implementation of TMFs could result in periodic reduction in habitat stability for native fish (e.g., razorback sucker) in nearshore habitats and slightly higher stranding of YOY rainbow trout. Temperature suitability under Alternative C would be similar to Alternative A for trout, native fishes, and growth of YOY humpback chub; but could slightly improve conditions for warmwater nonnative fish at the locations farthest downstream from Glen Canyon Dam. The greater number of HFEs, coupled with reduced fluctuations, under Alternative C compared to Alternative A could result in higher rainbow trout recruitment and emigration rates. Alternative C has the highest estimated number of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about 44,000 fish), and the fewest large rainbow trout (about 750 fish) relative to all of the other non-steady flow alternatives. The estimated average minimum number of adult humpback chub under Alternative C would be similar to that under Alternative A (about 5,000 adult fish), while the estimated absolute minimum number of adult humpback chub under Alternative C is about the same as Alternative A (1,500 fish). Experimental low summer flows could benefit humpback chub, razorback suckers, and other native fish that utilize nearshore habitats. There is also a potential for warmer water to increase the number of trout, warmwater nonnative fish, and warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

4.5.3.4 Alternative D (Preferred Alternative)

Impacts of Alternative D on Aquatic Food Base[13]

Under Alternative D, monthly release volumes would be relatively consistent throughout the year compared to Alternative A. This monthly release pattern would produce a more consistent and stable aquatic food base than under Alternative A, and daily range in flows would be similar to Alternative A. Therefore, benthic productivity may be somewhat increased, particularly in the Glen Canyon reach. Stranding within the varial zone may be somewhat lower under Alternative D compared to Alternative A as a result. Increased benthic productivity would increase drift in the long term (Kennedy, Yackulic et al. 2014).

Under Alternative D, there would be an average of 21.1 HFEs (maximum of 38 HFEs) (Table 4.3-1). The more frequent HFEs are expected to favor blackfly and midge production. Spring HFEs may not be tested in years when there appear to be unacceptable risks to key resources including the aquatic food base. Impacts on the aquatic food base from a proactive spring HFE would be similar to those under Alternative C (Section 4.5.3.3).

Under Alternative D, up to four of the fall HFEs could be extended-duration HFEs (lasting up to 250 hr). These extended-duration HFEs would be of higher magnitude and could produce more benthic scouring than the extended-duration HFEs for Alternative C. HFEs longer than 96 hr could help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance. The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE could scour the remaining primary producers and susceptible invertebrates and further delay the recovery of the aquatic food base. Primarily for this reason, sediment-triggered and proactive spring HFEs would not be implemented following an extended-duration fall HFE within the same water year.

Tests of low summer flows would be conducted under Alternative D in the second 10 years of the LTEMP if conditions warrant it (as described in Section 2.2.4). Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative D, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative D, TMFs would be tested and implemented, if tests are successful. TMFs could cause short-term increases in drift rates and slightly decrease primary production.

An aquatic resource–related experiment unique to Alternative D would be to test the effects of macroinvertebrate production flows in May through August on benthic

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[13] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on the aquatic food base.

macroinvertebrate production and diversity. It has been demonstrated that the large varial zone created by fluctuating flows limits recruitment of mayflies (order Ephemeroptera), stoneflies (order Plecoptera), and caddisflies (order Trichoptera), collectively referred to as EPT (Ephemeroptera-Plecoptera-Trichoptera), due to high egg mortality. For example, adult females of the mayfly genus *Baetis* land on rocks protruding from the water surface and then crawl underwater to lay their eggs on the underside of the rock. These rocks may become dry for up to 12 hr during a fluctuation cycle, and even brief desiccation (e.g., 1 hour) may result in complete mortality of mayfly eggs (Kennedy et al. 2016). Because EPT taxa deposit eggs principally along river edge habitats, eggs laid during stable low flows over the weekend would not be subjected to drying prior to their hatching, which typically occurs after days to weeks of incubation. Depending on the findings from the first test, this experiment could be repeated during the LTEMP period. In addition to potentially increasing EPT, macroinvertebrate production flows may enhance production of other aquatic food base organisms that have terrestrial adult life stages, such as dragonflies and true flies (including midges and blackflies). Some loss of benthic production is expected in the shoreline areas that remain dewatered over the weekend. If this results in an unacceptable risk to overall benthic production, the experiment might not be repeated.

Temperature impacts on the aquatic food base under Alternative D would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative D on Nonnative Fish[14]

Under Alternative D, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish is expected to be slightly higher because of slightly lower within-day flow fluctuations, especially during the winter. Stranding of YOY rainbow trout may be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability for trout under Alternative D was estimated to be similar to that under Alternative A at all locations (Figure 4.5-4), but could improve slightly compared to Alternative A for warmwater nonnative fish at the locations farthest downstream (Figure 4.5-5).

Alternative D has a much higher number of HFEs (average of 21.1 HFEs and a maximum of 38 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. This greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, could result in higher rainbow trout abundance and emigration rates (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). This alternative is

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[14] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer). The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition, and this reduction in frequency could reduce the number of trout produced under Alternative D. This reduction would not change the ranking of Alternative D relative to other alternatives with regard to effects on trout.

expected to result in average rainbow trout numbers of about 93,000 age-1 and older fish and 810 large rainbow trout, similar to those estimated for Alternative A, suggesting that inclusion of TMFs would offset the increased recruitment that would be anticipated with a greater occurrence of HFEs (see Appendix F). However, modeling results suggest that the number of trout emigrating into Marble Canyon under Alternative D (about 41,000 fish) would be about 11% higher, on average, than under Alternative A (about 37,000 fish) (Figure 4.5.2). TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative D, it is anticipated that TMFs would be triggered in about 4 out of 20 years, on average.

Mechanical removal of nonnative fish would be implemented in the Little Colorado River reach to lessen the effects of competition and predation on humpback chub by nonnative fish (especially trout) if abundance dropped below 7,000 adults (see Appendix O).[15] Once triggered, mechanical removal efforts would cease if a calculated relative predator index declines to 60 rainbow trout per kilometer in the vicinity of the Little Colorado River for 2 years or the number of adult humpback chub increase to more than 7,000. Modeling conducted for the EIS indicated that mechanical removal was effective in controlling trout numbers unless immigration rates into the Little Colorado River reach were high.

Alternative D is the only alternative to include macroinvertebrate production flows (low steady flows every weekend from May to August). These flows could improve the diversity and production of the aquatic food base for trout in the Glen Canyon reach and for warmwater nonnative fish.

Low summer flows would be included under Alternative D as an experiment during the second 10 years of the LTEMP period if triggered by low summer water temperatures and low humpback chub numbers. Providing warmer nearshore habitats could promote recruitment and survival of nonnative fish species that prey on or compete with native fish species. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of the Grand Canyon is currently low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of nonnative fish by warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

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[15] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

Impacts of Alternative D on Native Fish[16]

The quantity, quality, and stability of nearshore habitats would be affected less under Alternative D than under Alternative A because within-day flow fluctuations would be slightly less under this alternative than under Alternative A, especially during winter. Mainstem temperature suitability for humpback chub (Figure 4.5-6) and growth of YOY humpback chub under predicted mainstem temperatures (Figure 4.5-7) are expected to differ little from suitability and growth predicted for Alternative A. Temperature suitability for other native fish (including razorback sucker) could improve slightly compared to under Alternative A (Figure 4.5-9) because, under Alternative D, it is predicted that monthly volumes would result in more favorable mainstem temperatures at downstream locations (e.g., RM 225) during early summer months when spawning and egg incubation would benefit.

The relatively high number of HFEs under Alternative D would normally be expected to increase the recruitment levels for trout and the number of emigrants to the Little Colorado River reach (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). As discussed above, even though TMFs that would be implemented (when triggered by high predicted levels of recruitment) throughout the LTEMP period may result in smaller average trout population size in the Glen Canyon Reach, the model indicated that emigration of trout to the Marble Canyon reach under Alternative D would increase, on average, by about 11% compared to Alternative A. This increases the potential for trout to occur in the Little Colorado River reach where humpback chub survival and growth could be affected. The potential for competition with and predation on humpback chub by trout is expected to be partially offset by allowing mechanical removal of trout in the Little Colorado River reach when triggering conditions are met (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. Based on modeling, the estimated average minimum number of adult humpback chub under Alternative D (about 5,200 adult fish) would be about 4% higher than under Alternative A; 1 and 3% lower than under Alternatives E and B, respectively; and 11 and 18% higher than under Alternatives G and F, respectively (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative D is about 1,800. Predicted increases in humpback chub numbers under Alternative D could be bolstered by improvements in food base productivity resulting from more even monthly volumes and moderate fluctuations (see Section 4.5.2.1). While indirect benefits of TMFs for native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

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[16] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on native fish.

As identified in Section 2.2.4.6 and Appendix O, a number of experimental actions (referred to as Tier 1 actions) designed to improve rearing and recruitment of juvenile humpback chub would be implemented under Alternative D when adult humpback chub abundance declines to 9,000, or if recruitment of subadult humpback chub does not meet or exceed estimated adult mortality. Experimental actions would include expanded translocations of YOY humpback chub to grow-out areas within the Little Colorado River (i.e., above Chute Falls, Big Canyon), or larval humpback chub would be taken to a rearing facility and released in the mainstem Little Colorado River inflow area once they reach 150– 200 mm. Alternatively, YOY would immediately be translocated to areas with few predators for rearing, such as Big Spring or above Chute Falls. Based on past experience successfully translocating fish within the Little Colorado River and to tributaries, where translocated fish experienced high survival and/or growth rates (Healy et al. 2014; Spurgeon et al. 2015; Van Haverbeke et al. 2016), there is a high likelihood of beneficial effects on humpback chub through augmentation of the adult population as a result of these experimental actions. Detrimental effects on humpback chub, including fatality, could occur during handling, transport, or tempering; however, the number of these occurrences is generally low (a few individuals; see Appendix O).

Mechanical removal of nonnative fish would be implemented in the Little Colorado River reach to lessen the effects of competition and predation on humpback chub by nonnative fish, if Tier 1 actions failed to reverse declining trends and adult abundance dropped below 7,000. Past removal efforts appeared to be effective in controlling rainbow trout, and humpback chub recruitment increased; however, the removal effort coincided with a systemwide decline in trout abundance and warmer realeases from Glen Canyon Dam, which confounded results (Coggins et al. 2011).

Alternative D is the only alternative to include macroinvertebrate production flows (low steady flows every weekend from May to August). These flows could improve the diversity and production of the aquatic food base for native fish.

Low summer flows would be included under Alternative D as an experiment during the second 10 years of the LTEMP period, if triggered by low summer water temperatures and low humpback chub numbers. They are expected to increase warming and overall stability of nearshore habitats, potentially benefitting humpback chub, razorback suckers, and other native fish. Providing warmer nearshore habitats could also promote recruitment and survival of nonnative fish species, including trout, that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species, which could alter suitability for razorback sucker. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of the Grand Canyon are currently low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of native fish by warmwater fish parasites. Effects on parasites, nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

Alternative D is the only alternative to include macroinvertebrate production flows (low steady flows every weekend, May–August). As described above, these flows could have both beneficial and adverse effects on the food base, which could either increase or decrease native fish abundance.

Summary of Alternative D Impacts

The relatively similar monthly release volumes under Alternative D compared to Alternative A, and all other alternatives except Alternative G, would produce a more consistent and stable aquatic food base. Fluctuation levels would be comparable to those under Alternative A and would produce comparable varial zone conditions and benthic productivity. The more frequent HFEs under Alternative D are expected to favor midge and blackfly production compared to Alternative A. Macroinvertebrate production flows in May through August under Alternative D would be tested to determine if they increase benthic food base production and diversity including the recruitment of mayflies, stoneflies, and caddisflies (important food base organisms currently rare to absent throughout much of the mainstem below Glen Canyon Dam). Temperature impacts on the aquatic food base under Alternative D would be similar to those under Alternative C.

Under Alternative D, habitat quality and stability for nonnative and native fish are expected to be slightly higher than under Alternative A. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A. Temperature suitability for trout, humpback chub, and growth of YOY humpback chub under Alternative D would be similar to that under Alternative A, but could slightly improve suitability for warmwater nonnative fish and other native fish. The high number of HFEs could result in higher rainbow trout abundance and emigration rates. Alternative D is expected to result in average rainbow trout numbers of about 93,000 age-1 and older fish and 810 large rainbow trout, similar to those estimated for Alternative A. However, modeling results suggest that the number of trout emigrating into Marble Canyon under Alternative D (about 41,000 fish) would be about 11% higher, on average, than under Alternative A (about 37,000 fish). The estimated average minimum numbers of adult humpback chub under Alternative D (about 5,200 adult fish) would be higher than under Alternative A (5,000 adult fish). The estimated absolute minimum number of adult humpback chub over the LTEMP period under Alternative D is about 1,800 compared to 1,500 under Alternative A. Experimental low summer flows could benefit humpback chub, razorback suckers, and other native fish that utilize nearshore habitats. There is also a potential for warmer steadier flows associated with low summer flows to increase the number of trout, warmwater nonnative fish, and warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated. Implementation of Tier 1 experimental actions (e.g., expanded translocations and hatchery rearing and release of fish from the Little Colorado River) and mechanical removal of nonnative fish in the Little Colorado River reach if recruitment or adult populations of humpback chub fall below 7,000 would provide benefits for the humpback chub.

4.5.3.5 Alternative E

Impacts of Alternative E on Aquatic Food Base

More even monthly release volumes would improve aquatic food base productivity compared to Alternative A. However, this benefit could be offset by increased daily fluctuations, which would strand invertebrates within the varial zone. Higher daily fluctuations may also cause short-term increases in drift.

Under Alternative E, fall HFEs would be allowed throughout the 20-year LTEMP period, while spring HFEs would be allowed for the last 10 years of the LTEMP period, with an average of 17.1 HFEs (maximum of 30 HFEs) (Table 4.3-1). The frequent HFEs will favor blackfly and midge production. The number of HFEs would be less than under Alternative C because there would be no spring HFEs in the first 10 years (see Section 2.3). Steady flows would occur after significant sediment inputs prior to fall HFEs under Alternative E. Consequently, there could be several months of improved benthic production in the mainstem and possible maintenance and development of planktonic and benthic production in shoreline areas, especially backwaters.

Tests of low summer flows would be conducted under Alternative E in the second 10 years of the LTEMP if conditions warrant (as described in Section 2.2.5). Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative E, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative E, TMFs would be tested and implemented, if tests are successful. TMFs could increase cause short-term increases in drift rates and slightly decrease primary production.

Temperature impacts on the aquatic food base for Alternative E would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative E on Nonnative Fish

Under Alternative E, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish would be slightly lower due to increased levels of within-day fluctuations during most months. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability under Alternative E would be similar to suitability under Alternative A for trout at all locations, but would be slightly higher compared to Alternative A for warmwater nonnative fish at the locations farthest downstream. TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative E, it is anticipated that TMFs would be triggered in about 3 out of 20 years, on average.

Alternative E has more HFEs (average of 17.1 HFEs and a maximum of 30 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B, but fewer than the other alternatives. This greater number of HFEs is expected to result in relatively high rainbow trout abundance and emigration rates (see discussion of effects of HFEs in Section 4.5.2.2), although the greater levels of within-day fluctuations and the implementation of TMFs are expected to result in an overall reduction in age-1 and older fish (Figure 4.5-1), but slightly higher levels of emigration (about 38,000 fish/yr) compared to Alternative A (see discussion of effects of removal actions in Section 4.5.2.2). Slightly more large rainbow trout are expected (on average about 830 fish) than under Alternative A based on modeling results (Figure 4.5-3).

Low summer flows would be included under Alternative E as an experiment during the second 10 years of the LTEMP period, if triggered by low summer water temperatures and low humpback chub numbers. Providing warmer nearshore habitats could promote recruitment and survival of trout and warmwater nonnative fish that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of nonnative fish by warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

Impacts of Alternative E on Native Fish

Under Alternative E, habitat quality and stability for native fish would be slightly lower due to increased levels of within-day fluctuations during most months compared to Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), is expected to differ little from suitability and growth predicted for Alternative A.

Alternative E allows no spring HFEs for the first 10 years, but it has relatively similar numbers of fall HFEs compared to Alternatives C, D, F, and G. The relatively high number of HFEs under Alternative E would be expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2) with potential adverse effects on humpback chub. The potential for competition with and predation on humpback chub is expected to be partially controlled by mechanical removal of trout in the Little Colorado River reach (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. The modeled average minimum number of adult humpback chub under Alternative E (about 5,300 fish) was about 6% higher than under Alternative A (about 5,000 fish) (Figure 4.5-8), reflecting the combined effects on growth and survival of humpback chub associated with slightly higher emigration rates for trout from the Glen Canyon reach, slightly warmer mainstem temperatures at the confluence with the Little Colorado River, and implementation of mechanical removal of trout in the Little Colorado River reach when triggering criteria are met. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative E is about 1,600. However, predicted increases in humpback chub numbers could be offset by decreases in food base productivity resulting from higher fluctuations under Alternative E. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

Low summer flows included under Alternative E as an experiment after the first 10 years of the LTEMP period would likely increase warming and overall stability of nearshore habitats, potentially benefitting humpback chub, razorback suckers, and other native fish in the Grand Canyon. Providing warmer nearshore habitats could promote recruitment and survival of nonnative fish species, including trout, which prey on or compete with native fish species. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species that could alter suitability for razorback sucker. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of the Grand Canyon are currently low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of native fish by warmwater fish parasites. Effects on parasites, nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

Summary of Alternative E Impacts

Under Alternative E, relatively even monthly release volumes would increase aquatic food base productivity, but this increase could be offset by increased daily fluctuations. The number of HFEs under Alternative E would favor midge and blackfly production, though the number of HFEs would be less than under Alternative C. Temperature impacts on the aquatic food base for Alternative E would be similar to those under Alternative C.

Under Alternative E, habitat quality and stability for nonnative and native fish would be slightly lower than under Alternative A due to increased levels of within-day fluctuations during most months; implementation of TMFs could result in additional periodic reductions in habitat stability for native fish (e.g., razorback sucker) in nearshore areas. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A. Temperature suitability for trout, native fish, and growth of YOY humpback chub under Alternative E would be similar to that under Alternative A; but would be slightly higher for other warmwater nonnative fish species at locations farthest downstream from Glen Canyon Dam. The high number of HFEs under Alternative E is expected to result in relatively high rainbow trout abundance and emigration rates compared to Alternative A; although the greater levels of within-day fluctuations and the implementation of TMFs are expected to result in an overall reduction in age-1 and older fish but slightly higher levels of emigration compared to Alternative A. Slightly more large rainbow trout (830) are expected than under Alternative A (770). The modeled average minimum number of adult humpback chub under Alternative E (about 5,300 fish) is slightly higher than under Alternative A (about 5,000 fish). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative E is about 1,600, compared to 1,500 under Alternative A. Experimental low summer flows could benefit humpback chub, razorback suckers, and other native fish that utilize nearshore habitats. There is also a potential for warmer water to increase the number of trout, warmwater nonnative fish, and warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

4.5.3.6 Alternative F

Impacts of Alternative F on Aquatic Food Base

Compared to all other alternatives, Alternative F would have lower flow volumes, and therefore potentially less benthic biomass, from July through the following March. Seasonally adjusted steady flows would minimize the adverse effects of desiccation and dewatering that occurs in a varial zone (Reclamation et al. 2002). Flow stabilization may allow for very high snail densities, especially for the New Zealand mudsnail (Reclamation et al. 2002). In addition, reduced drift rates occur under mildly fluctuating or steady flows (Shannon et al. 1996; Rogers et al. 2003). Lower benthic productivity may also cause decreased drift over the long term (Kennedy, Yackulic et al. 2014). Higher volumes in April through June may increase benthic biomass compared to Alternative A, and would somewhat mimic pre-dam conditions with increased flows during spring and early summer. Increased benthic productivity during this period may also increase drift (Kennedy, Yackulic et al. 2014).

Under Alternative F, the 24-hr, 45,000-cfs high flows in early May in years without sediment-triggered spring HFEs, together with the May and June period of sustained high flows and the week-long 25,000 cfs release at the end of June, would scour the benthos, particularly within the Glen Canyon reach. This could improve the aquatic food base by reworking sediments and removing fines that can limit production of benthic organisms. Alternative F would have an average of 38.1 HFEs (maximum of 40 HFEs) (Table 4.3-1). The frequent HFEs will favor blackfly and midge production. Sustained high flows and HFEs would also decrease the density of New Zealand mudsnails.

No trout management actions would occur under Alternative F, but the rapid drop from high flows in June to low flows in July could have similar effects to those of TMFs. If these flow changes did not mimic the effects of TMFs, there would be continued competition for aquatic food base resources between trout and other fish species.

The warmer mean monthly water temperatures under Alternative F at RM 225 may slightly increase benthic production compared to all other alternatives, as modeled monthly summer temperatures would range from 18.6 to 20.5°C (65.5 to 68.9°F) for July through August. In addition to favoring adnate diatoms over stalked diatoms, these warmer temperatures would tend to favor *Oscillatoria* over *Cladophora*. These changes would be considered detrimental to the aquatic food base (Section 4.5.2.1). Otherwise, temperature impacts on the aquatic food base would be similar to those described for Alternative A (Section 4.5.3.1).

Impacts of Alternative F on Nonnative Fish

Because there would be no within-day flow fluctuations, Alternative F is expected to have positive effects on nonnative fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives. Although the results of the temperature suitability modeling show only small differences among the alternatives in overall suitability for trout, temperature suitability under Alternative F would be slightly greater, compared to Alternative A, at RM 61 and slightly lower at RM 157 and RM 225 (Figure 4.5-4). For warmwater nonnative fish, mainstem temperature suitability is expected to improve slightly, compared to Alternative A, at RM 61and RM 157 (Figure 4.5-5). The warmer temperatures at the downstream locations during summer and fall months may slightly increase the potential for successful reproduction, survival, and growth of warmwater nonnative fish compared to Alternative A.

Among all alternatives, Alternative F has the greatest average modeled population size of age-1 and older rainbow trout (about 160,000 fish) in the Glen Canyon reach (Figure 4.5-1), and the greatest average annual number of rainbow trout (about 72,000 fish/yr) emigrating from the Glen Canyon reach. These numbers reflect the more stable habitat conditions and very high number of HFEs (an average of 39 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) of this alternative that are expected to result in increased production and survival of YOY rainbow trout (see discussion of effects of HFEs in Section 4.5.2.2). Because this alternative does not include implementation of TMFs or mechanical removal, there is no offset to conditions that would be likely to increase recruitment, resulting in larger numbers but lower growth rates for trout in the Glen Canyon reach. There are expected to be, on average, fewer large rainbow trout (about 590 fish) under this alternative than under any of the other alternatives (Figure 4.5-3). The modeled results for Alternative F are consistent with results from an experiment conducted during the spring and summer of 2000 to examine effects of low summer steady flows (Ralston 2011). During that study, the abundance of some nonnative fish species (e.g., fathead minnow, plains killifish, and rainbow trout) increased following periods with reduced fluctuations and/or warmer water temperatures (Ralston 2011).

Impacts of Alternative F on Native Fish

Under Alternative F, there would be no within-day fluctuations in flow, resulting in a high degree of nearshore habitat stability. The 24-hr, 45,000-cfs peak flow in May, extended high flows of 20,000 cfs in May and June, and 7-day 25,000-cfs high flow at the end of June may improve forage for native fish by reworking sediments and removing fines that can limit production of benthic organisms. Compared to Alternative A, temperature suitability would be slightly higher at RM 61 and lower at RM 213. Temperature suitability for native fish would be lower at RM 225 (Diamond Creek) compared to other alternatives (Figure 4.5-9). Under Alternative F, modeling estimated that YOY humpback chub would achieve a total length of about 26 mm by the end of their first year at RM 61, and about 54 mm at RM 213 if rearing occurred in main channel habitats; this level of growth is slightly higher than that estimated for all other alternatives (Figure 4.5-7).

The minimum number of adult humpback chub under Alternative F (about 4,400 adult fish) was estimated to be lower than under any of the other alternatives (Figure 4.5-8). This lower estimated population size results from the high number of HFEs, low summer flows, and lack of within-day fluctuations that promote production of rainbow trout in the Glen Canyon reach and subsequent high emigration to the Marble Canyon reach (see Section 4.5.3.2), as well as the lack of TMFs or mechanical removal that could offset increases in trout. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative F is about 1,400. Frequent spring HFEs would also contribute to the periodic reworking of sediments and creation of backwater habitat in the lower Grand Canyon during a time that may coincide with spawning and emergence of larval razorback sucker.

Historically, there have been few opportunities to study the effects of steady-flow operations on fish resources downstream of Glen Canyon Dam, especially the effects of long-term steady flow operations. During the spring and summer of 2000, a series of steady discharges of water from Glen Canyon Dam were used to evaluate effects of aquatic habitat stability and water temperatures on native fish growth and survival, with a particular focus on the humpback chub (Ralston 2011). The hydrograph implemented for the experiment achieved steady discharges at various levels that lasted for periods of 4 days to 8 weeks. The steady flows did not appear to result in increased growth rates by humpback chub or other native fish, although there was some evidence that nonnative fish species that could compete with or prey upon native fish species (fathead minnow, plains killifish, and rainbow trout) experienced population increases associated with reduced fluctuations and/or warmer water temperatures that occurred during the experimental period (Ralston 2011). However, the short-term nature of the experiment makes it difficult to draw conclusions about what effects a multi-year steady flow operation would have. Given the need for warm, productive nearshore (including backwater) habitats for rearing of larval and juvenile native fishes, and the lack or low abundance of nonnative fish found in recent backwater sampling (Albrecht et al. 2014; Kegerries et al. 2015), reduced fluctuations during spring and summer months may be beneficial for razorback sucker by providing warm and persistent backwater habitats.

Summary of Alternative F Impacts

Under Alternative F, food base biomass from July through the following March would be potentially less compared to all other alternatives due to comparatively lower flow volumes. Flow stabilization may allow for high benthic densities of New Zealand mudsnails, while reduced benthic productivity is expected to reduce drift. Higher flow volumes in April through June may increase benthic food base biomass and drift compared to Alternative A. The frequent HFEs will favor blackfly and midge production. The warmer water temperatures for August and September at RM 225 under Alternative F may slightly increase food base production even more than Alternative D, although this could similarly be offset by change in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

Alternative F is expected to have positive effects on nonnative and native fish (including humpback chub and razorback sucker) and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives. Temperature suitability for nonnative and native fish under Alternative F would be slightly higher than Alternative A at RM 61 and slightly lower at sites further downstream. The warmer temperatures at the downstream locations during summer and fall months may slightly increase the potential for successful reproduction, survival, and growth of warmwater nonnative fish compared to Alternative A. Among all alternatives, Alternative F has the greatest average modeled population size of age-1 and older rainbow trout (about 160,000 fish) in the Glen Canyon reach, and the greatest average annual number of rainbow trout (about 72,000 fish/yr) emigrating from the Glen Canyon reach. There are expected to be, on average, fewer large rainbow trout (about 590 fish) under this alternative than under any of the other alternatives. The minimum number of adult humpback chub under Alternative F (about 4,400 adult fish) was estimated to be lower than under any of the other alternatives. The estimated absolute minimum number of adult humpback chub under Alternative F is about 1,400.

4.5.3.7 Alternative G

Impacts of Alternative G on Aquatic Food Base

Under Alternative G, changes in monthly release volumes would be limited only to those necessary to adjust to changes in runoff forecasts. The benthic community would benefit from these even monthly volumes and the steady within-day flows of this alternative. This would allow somewhat consistent and stable aquatic food base conditions to persist throughout the year. In addition, benthic community biomass would probably be greater under Alternative G compared to Alternative F, because flows from July through the following February would be higher under Alternative G. However, the year-round stable conditions may favor dominance by less-desirable species such as the New Zealand mudsnail. Increased benthic production could result in long-term increases in drift (Kennedy, Yackulic et al. 2014).

Alternative G would have an average of 24.5 HFEs (maximum of 40 HFEs) (Table 4.3-1). The frequent HFEs are expected to favor blackfly and midge production. HFEs would also decrease the density of New Zealand mudsnails. Impacts on the aquatic food base from proactive spring HFEs would be similar to those under Alternative C (Section 4.5.3.3).

Under Alternative G, there could be fall HFEs of up to 45,000 cfs that could last as long as 336 hr. These extended-duration HFEs would be of higher magnitude and could produce more benthic scouring than the extended-duration HFEs for Alternative C. HFEs longer than 96 hr may help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance.

The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE, particularly a long-duration HFE, could scour the remaining primary producers and susceptible invertebrates and further delay the recovery of the aquatic food base. For this reason, implementation of a spring HFE in years that follow an extended-duration fall HFE would be carefully considered.

Trout removal, as would occur under Alternative E, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative G, TMFs would be tested and implemented, if tests are successful. TMFs could cause short-term increases in drift rates and slightly decrease primary production.

Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative G on Nonnative Fish

Under Alternative G, there would be no within-day fluctuations, and monthly volumes would only vary as a result of changes in runoff forecasts. As a result, habitat stability would be greater under this alternative than under any of other alternatives. Under this alternative, trout would continue to be supported in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to occur in the lower portions of the river and tributaries. Similar to Alternative F, improved temperature suitability in the lower reaches of the river could increase the potential for successful spawning of warmwater nonnative fishes in nearshore main channel habitats. TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative G, it is anticipated that TMFs would be triggered in about 11 out of 20 years, on average.

The annual population size of rainbow trout in the Glen Canyon reach is expected to be higher under Alternative G than under any of the non-steady flow alternatives, and only slightly less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively). Similarly, the estimated annual number of rainbow trout emigrating from the Glen Canyon reach to the Marble Canyon reach is greater than under any of the non-steady flow alternatives, and second only to Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). The relatively high abundance and emigration rate reflect, in part, the high number of HFEs that could occur with this alternative (an average of 24.5 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period), including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, and the absence of within-day fluctuations. However, TMFs and mechanical removal of trout, which are included as operational elements in this alternative, are expected to partially mitigate the increased trout production.[17] Alternative G would have the second-lowest average number of large rainbow trout (about 690 fish >16 in. total length) (Figure 4.5-3). The modeled results for nonnative fish under Alternative G are consistent with results from an experiment conducted during the spring and summer of 2000 to examine effects of low summer steady flows (Ralston 2011). During that study, the abundance of some nonnative fish species (e.g., fathead minnow, plains killifish, and rainbow trout) increased following periods with reduced fluctuations and/or warmer water temperatures (Ralston 2011). However, the short-term nature of the experiment that was conducted makes it difficult to draw conclusions about what effects a multi-year steady flow operation would have.

Impacts of Alternative G on Native Fish

Under Alternative G, habitat stability for native fish (including humpback chub and razorback sucker) would be greater than under any of the other alternatives. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ little from suitability and growth predicted for Alternative A.

The high number of HFEs under Alternative G is expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach, with potential adverse effects on humpback chub. The potential for competition with and predation of humpback chub are expected to be partially offset by mechanical removal (when triggering criteria are met) of trout in the Little Colorado River reach. However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. Modeling indicated that the average minimum number of adult humpback chub (about 4,700 adult fish) under Alternative G would be the second lowest value of all alternatives and would be approximately 6% lower than under Alternative A (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative G is about 1,700. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources. For information regarding past studies of the effects of steady-flow operations on native fish downstream of Glen Canyon Dam, refer to Section 4.5.3.6.

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[17] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

Summary of Alternative G Impacts

Under Alternative G, somewhat consistent and stable aquatic food base conditions to persist throughout the year. Benthic food base biomass and drift would probably be greater under Alternative G compared to Alternative F, because flows from July through the following February would be higher. However, stable flows may favor dominance by the New Zealand mudsnail. Potentially higher drift rates from spring flows under Alternative F would not occur under Alternative G. The frequent HFEs are expected to favor blackfly and midge production. Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternative C.

Habitat stability for nonnative and native fish (including humpback chub and razorback sucker) would be greater under Alternative G than under any of the other alternatives. Similar to Alternative F, improved temperature suitability in the lower reaches of the river could increase the potential for successful spawning of warmwater nonnative fishes in nearshore main channel habitats; whereas, temperature suitability for native fishes, as well as growth of YOY humpback chub, are expected to differ little from Alternative A. The annual population size of rainbow trout in the Glen Canyon reach is expected to be higher under Alternative G than under any of the non-steady flow alternatives, and only slightly less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively). Similarly, the estimated annual number of rainbow trout emigrating from the Glen Canyon reach to the Marble Canyon reach is greater than under any of the non-steady flow alternatives, and second only to Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). Alternative G would have the second-lowest average number of large rainbow trout (about 690 fish >16 in. total length). The average minimum number of adult humpback chub (about 4,700 adult fish) under Alternative G would be the second lowest value of all alternatives. The estimated absolute minimum number of adult humpback chub under Alternative G is about 1,700.

4.6 VEGETATION

This section presents an evaluation of the impacts of the LTEMP on riparian vegetation of the Colorado River corridor between Glen Canyon Dam and Lake Mead. Glen Canyon Dam operations affect river flow and stage, which in turn affect the disturbance regime, soil moisture, and ultimately the distribution of vegetation species and communities in the river corridor. In addition to the effects of operations on vegetation communities, the effects on vegetation of non-flow actions were evaluated, including vegetation treatments. Analysis methods, a summary of anticipated impacts, and alternative specific impacts are presented.

4.6.1 Analysis Methods

Issue: How do alternatives affect riparian vegetation in the project area as a result of dam operations?

Impact Indicators:

- Changes in habitat of special status plant species
- Changes in cover of wetland community types
- Changes in the composition of the New High Water Zone and wetland vegetation as indicated by four metrics: (1) change in cover of native community types; (2) change in diversity of native community types; (3) change in the ratio of native to nonnative community types; and (4) change in the arrowweed community type
- Change in the composition of plant communities in the Old High Water Zone

Three sources of information were evaluated in order to analyze the impacts of the alternatives on plant communities. First, information found in studies on vegetation done to date was examined. Secondly, a model based on published studies and collected data was used to predict potential effects. Third, the combined information from the studies and model was evaluated to analyze the potential effects of the alternatives over the period of the LTEMP. The studies allowed an assessment of effects that go beyond the limitations of the model.

The model enabled an evaluation of effects by predicting four characteristics of vegetation. The metrics that reflect these characteristics were calculated using the results of an existing model for Colorado River riparian vegetation downstream of the Paria River (Ralston et al. 2014). Seven vegetation states were used in the model to represent plant community types found along the river on sandbars and channel margins in the New High Water Zone and Fluctuation Zone (Section 3.6). Species associated with a particular state respond similarly to Colorado River hydrologic factors such as depth, timing, and duration of inundation. These states and the plant species associated with each are given in Table 4.6-1. The model and data used to calculate performance metrics are based on vegetation studies conducted within GCNP (see citations in Ralston et al. 2014). Although the model is a simplification of the complexities of the riparian ecosystem, it is a valuable tool for assessing potential changes in riparian vegetation under a variety of flow regimes. Model details are described in Ralston et al. (2014). The four metrics are:

1. Relative change in cover of native-dominated vegetation community types (other than arrowweed) on sandbars and channel margins using the total percentage increase in native states (change in native cover = $\text{cover}_{\textit{final}}/\text{cover}_{\textit{initial}}$; a result >1 is a beneficial change).

2. Relative change in diversity of native vegetation community types (other than arrowweed) on sandbars and channel margins using the Shannon Weiner index for richness/evenness (change in diversity = $\text{diversity}_{\textit{final}}/\text{diversity}_{\textit{initial}}$; a result >1 is a beneficial change).

TABLE 4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels

Vegetation States	Primary Plant Species	Additional Species	Submodel/Landform
Bare Sand	<1% vegetation cover		All submodels
Common Reed Temperate Herbaceous Vegetation (Marsh)	Common reed (*Phragmites australis*), cattail (*Typha domingensis, T. latifolia*)	Common tule (*Schoenoplectus acutus*), creeping bent grass (*Polypogon viridis*)	Lower Reattachment Bar
Coyote Willow-Emory Seep Willow Shrubland/ Horsetail Herbaceous Vegetation (Shrub Wetland)	Horsetail (*Equisetum laevigatum*), coyote willow (*Salix exigua*), *Baccharis emoryi*, *Schoenoplectus pungens*	*Eleocharis palustris, Muhlenbergia asperifolia*	Lower Channel Margin, Lower Reattachment Bar
Tamarisk Temporarily Flooded Shrubland	Tamarisk (*Tamarix* spp.)		All submodels
Cottonwood/Coyote Willow Forest[a] (Cottonwood-willow)	Coyote willow, cottonwood (*Populus fremontii*)	*Salix gooddingii, Baccharis salicifolia, Distichlis spicata, Muhlenbergia asperifolia, Phragmites australis*, *Equisetum spp., Juncus* spp., *Carex* spp., *Elaeagnus angustifolia, Tamarix* spp., *Agrostis stolonifera, Melilotus* spp.	Lower Channel Margin, Lower Separation Bar
Arrowweed Seasonally Flooded Shrubland (Arrowweed)	Arrowweed (*Pluchea sericea*)	*Baccharis* spp., mesquite (*Prosopis glandulosa*), coyote willow	Lower Reattachment Bar, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin
Mesquite Shrubland (Mesquite)	Mesquite (*Prosopis glandulosa* var. *torreyana*)	*Baccharis* spp., *Pluchea sericea*	Lower Channel Margin, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin

[a] Although an element of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

Source: Ralston et al. (2014).

3. Relative change in the ratio of native- (other than arrowweed) to nonnative-dominated vegetation community types on sandbars and channel margins (change in native/nonnative ratio = $\text{ratio}_{final}/\text{ratio}_{initial}$; a result >1 is a beneficial change).

4. Relative change in the arrowweed community type on sandbars and channel margins using the total percentage decrease in the arrowweed state (change in arrowweed = $\text{arrowweed}_{initial}/\text{arrowweed}_{final}$; a result >1 is a beneficial change). Because the desired change is a decrease in arrowweed, this metric is calculated as initial/final, unlike the other metrics.

These performance metrics were developed from the resource goal for riparian vegetation downstream of Glen Canyon Dam: *Maintain native vegetation and wildlife habitat in various stages of maturity that are diverse, healthy, productive, self-sustaining, and ecologically appropriate*.

The vegetation model has several limitations that should be noted when considering the modeling results. The model was designed as a conceptual as opposed to a predictive model; therefore, the results are used in this analysis carefully and in combination with the literature because the model is a simplification with limitations in the ability to assess on-the-ground changes. However, it is the best available tool for impact analysis, when used in conjunction with field studies and literature.

Several issues that could not be addressed by the model are discussed qualitatively or quantitatively based on literature from field studies in this section below. These include the dynamics of the tamarisk leaf beetle (*Diorhabda* spp.) on tamarisk distribution and abundance; the overall decrease in area of the Old High Water Zone and the mortality of species within that zone; the increase or decrease of open sand that could not be captured in this model, as it could not be coupled with the sediment models; the effects from NPS's experimental vegetation treatment program (common to most alternatives); and the fact that the model considers hypothetical sandbars and was not spatially explicit in relation to current and potential future conditions.

The vegetation model was developed to compare the effects of various flow regimes on Colorado River riparian vegetation. The model consists of six geomorphic submodels based on landforms that are known to influence vegetation floristics and structure: Lower Separation Bar, Upper Separation Bar, Lower Reattachment Bar, Upper Reattachment Bar, Lower Channel Margin, and Upper Channel Margin. The upper and lower landform surfaces are separated at the 25,000-cfs stage elevation (see Section 3.3.1.1 for a description of these landforms).

The four vegetation states dominated by native plant species are marsh (Common Reed Temperate Herbaceous Vegetation), shrub wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation), cottonwood-willow (Cottonwood/Coyote Willow Forest), and mesquite (Mesquite Shrubland). Although arrowweed is a native species, prior to the dam's construction, it was strongly controlled by spring flooding and was not common, but with cessation of spring floods it has invaded many sandbars and formed monocultures. Because of this tendency to form monocultures under these conditions, arrowweed (Arrowweed Seasonally Flooded Shrubland) states are excluded from the desired native states in the metrics. One nonnative state, tamarisk (Tamarisk Temporarily Flooded Shrubland), is included in the model. Bare Sand is also included as one of the possible states in the model. As described in Section 3.6, a number of other plant community types also occur within the riparian area downstream of Glen Canyon Dam (see also Table H-3). These plant community types vary somewhat by river reach, in the Old High Water Zone, New High Water Zone, and Fluctuation Zone.

In the model, the magnitude and timing of various important hydrologic events were identified for each model run and evaluated for the potential effects on vegetation (see Table G-2 in Appendix G for a listing and description of these hydrologic events). The model uses the daily maximum flow for the evaluation of each alternative. Important hydrologic events included spill flows (>45,000 cfs), spring HFEs (>31,500 to 45,000 cfs), fall HFEs (>31,500 to 45,000 cfs), extended low flows (daily maximum ≤10,000 cfs for at least 30 consecutive days), extended high flows (daily maximum ≥20,000 cfs for at least 30 consecutive days), and flows that can fluctuate up to 25,000 cfs, (i.e., the absence of spill flows or extended high or extended low flows). Although periodic spill flows (>45,000 cfs) could occur based on historic hydrologic conditions within the 20-year period of this evaluation, these would likely be infrequent and would occur at equal frequency under all alternatives. These spill flows are non-discretionary emergency actions and are not part of the alternatives, but were part of the hydrologic modeling. The timing of these events relative to the growing season (May–September) or non-growing season (October–March) was also determined. Growing seasons vary depending on the reach, but were generalized to these months for the model.

Daily fluctuation patterns generally produce the extended high and extended low flows. For example, Alternative B, with relatively large fluctuations, has a higher frequency of daily maxima ≥20,000 cfs for at least 30 consecutive days, and therefore more extended high flows; Alternatives F and G, two alternatives with no fluctuations, have a higher frequency of extended low flows. Monthly release volumes also affect these events. Alternative C, for example, has relatively small fluctuations but also low release volumes August through November, resulting in a higher frequency of extended low flows than Alternative G.

The model predicts transitions from one state to another, based on a set of rules that considers the frequency and duration of hydrologic events. The transition rules for the upper portions of the bars and channel margin are the same because of the similarity of plant community types and responses to flow characteristics. These transition rules are based on the effects of scouring, drowning, desiccation, and sediment deposition on riparian plant species. HFEs result in sediment deposition, but scouring is minor and limited to low-elevation wetland species (Kearsley and Ayers 1999; Ralston 2010; Stevens et al. 2001). HFEs transport seeds of nonnative as well as native species (Kennedy and Ralston 2011; Ralston 2011; Spence 1996). Repeated extended high flows (i.e., flows with daily maximum ≥20,000 cfs for at least 30 consecutive days) result in removal of vegetation by drowning and scouring, primarily on lower elevation surfaces (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010). Increased soil moisture at upper elevations from extended high flows can increase vegetation growth and seedling establishment (Waring 1995; Sher et al. 2000; Mortenson et al. 2012). The germination of seeds transported by HFEs or extended high flows is promoted by extended low flows (e.g., elevated base flows) that reduce disturbance, expose lower elevation surfaces, and maintain soil moisture at lower elevations, all of which are conducive to seedling growth (Porter 2002; Ralston 2011). Extended low flows (i.e., flows with daily maximum ≤10,000 cfs for at least 30 consecutive days) also can result in the lowering of groundwater levels, thus increasing the depth to groundwater and the reduction of soil moisture, creating conditions that favor the growth of more drought-tolerant species (Porter 2002; Stevens et al. 1995).

Model results include the total number of years each state occurs for the 20-year period of the model run according to each potential starting state in each submodel. For example, the reattachment bar submodel uses five different starting states for each hydrologic trace: bare sand, marsh, shrub wetland, tamarisk, and arrowweed. Model results were used to calculate the metrics for each alternative using the sum of each of the states for all six models. This value was then compared to the number of years each state would have accumulated, if the current condition was maintained, i.e., if no transitions occurred and each of the seven states remained the same for the full 20 years of the model run. This proportion was multiplied by the acreage of mapped cover types from the NPS Vegetation Map of GCNP (Kearsley et al. 2015) corresponding to the seven model states in order to provide a sense of the relative spatial scale of potential changes under each Alternative (Table 4.6-2). Because, as noted above, the model considers hypothetical sandbars due to the very dynamic nature of sand deposition and erosion in the canyon, the model cannot be used to accurately predict changes in total bare sand or riparian vegetation area, and results should only be used to determine the relative contribution of vegetation states to total area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a sense of the overall scale of vegetation changes, but do not represent actual predicted changes in area.

The results for the four metrics were then summed to derive a final score for each alternative. Alternatives with higher scores were considered to have come closer to achieving the resource goal. Several factors other than the operational characteristics considered by the models have a strong influence on the riparian vegetation below the dam, however, due to a lack of information on these potential effects and for the purposes of this analysis, it is assumed that these effects would apply equally across all alternatives. These include changes in precipitation, defoliation of tamarisk by the tamarisk leaf beetle and other insects, and experimental vegetation management activities implemented by the NPS to reduce invasive plant populations and increase local populations of desired native plants (Figure 4.6-1). The impacts of these factors were assessed in light of the potential vegetation changes shown by the state and transition model.

4.6.2 Summary of Impacts

Impacts on plant communities of the Old High Water Zone, New High Water Zone, and wetlands for the 20-year LTEMP period are summarized below. Table 4.6-3 provides an overview of the anticipated impacts by alternative, as well as the important flow characteristics associated with the effects of each alternative. Although the presence of the dam affects the vegetation community in the Colorado River Ecosystem via changes in maximum annual flows

TABLE 4.6-2 Vegetation States and Corresponding Mapped Vegetation Types

Vegetation States	Mapped Vegetation Classes[a]	Area (ac)
Bare Sand	Unvegetated Surfaces and Built Up Areas	112
Marsh (Common Reed Temperate Herbaceous Vegetation)	*Phragmites australis* Western North America Temperate Semi-Natural Herbaceous Vegetation	4.4
Shrub Wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation)	Arid West Emergent Marsh	0.2
Tamarisk (Tamarisk Temporarily Flooded Shrubland)	*Tamarix* spp. Temporarily Flooded Semi-Natural Shrubland	273.7
Cottonwood-Willow (Cottonwood/Coyote Willow Forest[b])	*Baccharis* spp.–*Salix exigua*–*Pluchea sericea* Shrubland Alliance	177.3
Arrowweed (Arrowweed Seasonally Flooded Shrubland)	*Baccharis* spp.–*Salix exigua*–*Pluchea sericea* Shrubland Alliance	177.3
Mesquite (Mesquite Shrubland)	*Prosopis glandulosa* var. *torreyana* Shrubland	137.1

[a] Kearsley et al. (2015), which mapped RM 0-278; vegetation classes and area are based on 2007 and 2010 aerial photography and do not necessarily reflect current conditions. This mapping was limited to GCNP and did not include Glen Canyon.

[b] Although a component of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

and sediment supply, the analysis conducted for the EIS indicated that vegetation areal cover, species composition, and diversity in the New High Water Zone are related to dam operations.

Figure 4.6-2 compares the predicted effects of each alternative on vegetation characteristics as measured using four metrics. A score of 1 indicates no change from initial conditions; values >1 indicate an improvement relative to current conditions (increase in native cover, native diversity, or native/nonnative diversity; decrease in arrowweed); values <1 indicate a decline relative to current conditions (decrease in native cover, native diversity, or native/nonnative ratio; increase in arrowweed), and Figure 4.6-3 presents the overall impacts under the LTEMP alternatives. In this case, a total score of 4.0 calculated by summing the scores for each of the 4 metrics under each alternative indicates no change from initial conditions; values >4 indicate an improvement relative to current conditions; and values <1 indicate a decline relative to current conditions. See Appendix G for additional details regarding the application of the vegetation model in the analysis of impacts.

TABLE 4.6-3 Summary of Impacts of LTEMP Alternatives on Vegetation

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Overall index = 3.66, reflecting an adverse impact relative to current condition resulting from: narrowing of Old High Water Zone; an expected decrease in New High Water Zone native plant community cover, decrease in native diversity, increase in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Compared to Alternative A, 6% increase in overall index reflecting an improvement in vegetation conditions (but a decline under hydropower improvement flows); impacts include a narrowing of the Old High Water Zone, decrease in New High Water Zone native plant community cover, increase in arrowweed, increase in native diversity (decrease under hydropower improvement flows), increase in native/nonnative ratio (decrease under hydropower improvement flows), and decrease in wetland community cover.	Compared to Alternative A, 13% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone; decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, decrease in arrowweed, and decrease in wetland community cover.	Compared to Alternative A, 8% increase in overall index reflecting an improvement in vegetation conditions; impacts include a narrowing of the Old High Water Zone, decrease in New High Water Zone native plant community cover, increase in native diversity, decrease in native/nonnative ratio, decrease in arrowweed, and decrease in wetland community cover; lowest impact of alternatives.	Compared to Alternative A, 3% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone, decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, increase in arrowweed, and decrease in wetland community cover.	Compared to Alternative A, 14% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative), decrease in arrowweed, and decrease in wetland community cover; highest impact of alternatives.	Compared to Alternative A, 7% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, decrease in arrowweed, and decrease in wetland community cover.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Old High Water Zone							
	Relative to current conditions, continued narrowing of zone due to lack of sufficiently high flows.	Same as Alternative A.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transiton between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but annual spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands [a]							
Relative change in cover of native vegetation community types (final cover/ initial cover)	Native cover index = 0.827, reflecting a 17% (55.2 ac[a]) overall decrease in native plant community cover over the LTEMP period relative to current conditions, resulting from few spring HFEs, occasional fall HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows; 28% (1.3 ac) decrease in wetland community cover resulting from extended high flows.	Compared to Alternative A, 3% increase in native cover index reflecting a smaller overall decrease (15%, 48.3 ac) in native plant community cover (47% decrease under hydropower improvement flows) resulting from few spring HFEs, more fall HFEs, slightly more extended high flows; 20% (0.9 ac) decrease in wetland community cover (83% [3.8 ac] decrease under hydropower improvement flows) resulting from extended high flows.	Compared to Alternative A, 24% decrease in native cover index reflecting a greater overall decrease (37%, 117.7 ac) in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 75% (3.4 ac) decrease in wetland community cover resulting from extended low flows and extended high flows (highest impact of all alternatives).	Compared to Alternative A, 6% increase in native cover index reflecting a smaller overall decrease (12%, 39.5 ac) in native plant community cover, resulting from more HFEs, more seasons without extended high or low flows, frequent extended high flows; 16% (0.8 ac) decrease in wetland community cover resulting from extended high flows (lowest impact of all alternatives).	Compared to Alternative A, 3% decrease in native cover index reflecting a greater overall decrease (20%, 63.5 ac) in native plant community cover, resulting from more fall HFEs, slightly more growing-season extended low flows; 38% (1.7 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Compared to Alternative A, 15% decrease in native cover index reflecting a greater overall decrease (30%, 95.0 ac) in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 86% (4.0 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Compared to Alternative A, 15% decrease in native cover index reflecting a greater overall decrease (29%, 93.7 ac) in native plant community cover, resulting from more HFEs, more extended low flows, occasional extended high flows; 58% (2.6 ac) decrease in wetland community cover resulting from extended low flows and extended high flows.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands ^{a} ***(Cont.)***							
Relative change in diversity of native vegetation community types (final diversity/ initial diversity)	Diversity index = 0.983, reflecting a 2% decrease in native diversity over the LTEMP period relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities resulting from occasional growing-season extended low flows.	Compared to Alternative A, 4% increase in diversity index reflecting an increase (3%) in native diversity relative to current conditions due to an increase in relative evenness of community types resulting from a small (<1 ac) decrease in wetlands (9% decrease under hydropower improvement flows) (lowest impact of all alternatives).	Compared to Alternative A, 6% decrease in diversity index reflecting a greater decrease (8%) in native diversity relative to current conditions, due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities in response to fewer seasons without extended high or low flows, more extended low flows.	Compared to Alternative A, 3% increase in diversity index reflecting an increase (2%) in native diversity relative to current conditions, due to an increase in relative evenness of community types resulting from a small (<1 ac) decrease in wetlands.	Compared to Alternative A, <1% decrease in diversity index reflecting a slightly greater decrease (2%) in native diversity relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities in response to slightly more growing-season extended low flows.	Compared to Alternative A, 8% decrease in diversity index reflecting a greater decrease (9%) in native diversity relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities in reponse to fewer seasons without extended high or low flows, more extended low flows (highest impact of all alternatives).	Compared to Alternative A, 2% decrease in diversity index reflecting a greater decrease (3%) in native diversity relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Relative change in the ratio of native- to nonnative-dominated vegetation community types (final ratio/initial ratio)	Native-nonnative index = 1.051, reflecting a 5% increase in ratio over the LTEMP period relative to current conditions reflecting a 58.4-ac decrease in tamarisk over the LTEMP period resulting from frequent extended high flows, few extended low flows, and spring HFEs. Tamarisk leaf beetle may increase benefit, but lack of experimental vegetation treatment provided under other alternatives would not provide benefit.	Compared to Alternative A, 9% increase in index (decrease under hydropower improvement flows), reflecting a 48.3-ac decrease in native cover but a larger 71.4 ac decrease in tamarisk (107 ac decrease under hydropower improvement flows) resulting from few spring HFEs, slightly more extended high flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk further. Lowest impact of alternatives.	Compared to Alternative A, 57% decrease in ratio, reflecting a 117.7 ac decrease in native cover and a 104-ac increase in tamarisk resulting from more HFEs, fewer seasons without extended high or low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk.	Compared to Alternative A; 9% decrease in ratio, reflecting a 39.5 ac decrease in native cover and a smaller 22.4-ac decrease in tamarisk resulting from extended high flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk further.	Compared to Alternative A; 9% decrease in ratio, reflecting a 63.5 ac decrease in native cover and a smaller 45.7-ac decrease in tamarisk resulting from more fall HFEs, slightly more growing-season extended low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease adverse impact.	Compared to Alternative A, 64% decrease in ratio, reflecting a 95 ac decrease in native cover and a 231-ac increase in tamarisk resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk. Highest impact of alternatives.	Compared to Alternative A; 43% decrease in ratio reflecting a 93.7 ac decrease in native cover and a 46.4-ac increase in tamarisk resulting from more HFEs, more extended low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Relative change in the arrowweed community type (initial acres/final acres)	Arrowweed index = 0.799, reflecting a 25% (44.5 ac) increase in arrowweed over the LTEMP period relative to current conditions resulting from few spring HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows. Highest impact of alternatives.	Compared to Alternative A, 5% increase in arrowweed index, reflecting a smaller increase (19%, 33.3 ac) in arrowweed relative to current conditions resulting from more extended high flows (24% increase under hydropower improvement flows). Non-flow vegetation treatment activities may decrease adverse impact.	Compared to Alternative A, 46% increase in arrowweed index, reflecting a decrease (14%, 25.1 ac) in arrowweed relative to current conditions resulting from repeated extended low flows and extended high flows. Non-flow vegetation treatment activities may increase benefit. Lowest impact of alternatives.	Compared to Alternative A, 39% increase in arrowweed index, reflecting a decrease (10%, 17.1 ac) in arrowweed relative to current conditions resulting from repeated extended high flows, frequent fall HFEs, and few growing season extended low flows. Non-flow vegetation treatment activities may increase benefit.	Compared to Alternative A; <1% change in arrowweed index, reflecting an increase (25%, 44.0 ac) increase in arrowweed relative to current conditions resulting from more HFEs, more growing-season extended low flows, and frequent growing-season extended high flows. Non-flow vegetation treatment activities may decrease adverse impact.	Compared to Alternative A; 43% increase in arrowweed index, reflecting a decrease (13%, 22.2 ac) in arrowweed relative to current conditions resulting from more HFEs, repeated extended high flows. Non-flow vegetation treatment activities may increase benefit.	Compared to to Alternative A; 41% increase in arrowweed index, reflecting a decrease (11%, 20.1 ac) in arrowweed relative to current conditions resulting from more HFEs, growing-season extended low flows, fewer growing-season extended high flows. Non-flow vegetation treatment activities may increase benefit.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Special status plant species[b]	No change from current conditions in terms of impacts on species of active and inactive floodplains; potential impact on wetland species resulting from continuing loss (28%, 1.3 ac) of wetland habitat.	Compared to Alternative A, no change from current conditions in terms of impacts on species of active and inactive floodplains; less impact on wetland species because less wetland habitat would be lost (20%, 0.9 ac).	Compared to to Alternative A, potential impacts on active floodplain species from extended-duration HFEs, greater impact onwetland species from 75% (3.4 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs.	Compared to Alternative A, potential impacts on active floodplain species from extended-duration HFEs, less impact on wetland species from 16% (0.8 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs.	Compared to Alternative A, similar impact on active floodplain species; greater impact on wetland species from 38% (1.7 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs (lowest impact of alternatives).	Compared to Alternative A, potential impacts on active floodplain species from annual HFEs; Lake Mead shoreline species from high reservoir levels; greater impact on wetland species from 86% (4.0 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs (highest impact of alternatives).	Compared to Alternative A,, potential impacts on active floodplain species from extended-duration HFEs; greater impact onwetland species from 58% (2.6 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs.

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[a] Changes in area are presented for each community type; however, because of the very dynamic nature of sand deposition and erosion in the canyon, the model cannot be used to accurately predict changes in total bare sand or riparian vegetation area and results should only be used to determine the relative contribution of vegetation states to total area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a sense of the overall scale of vegetation changes, but do not represent actual predicted changes in area.

[b] Details regarding special status plant species are provided in Table 4.6-6.

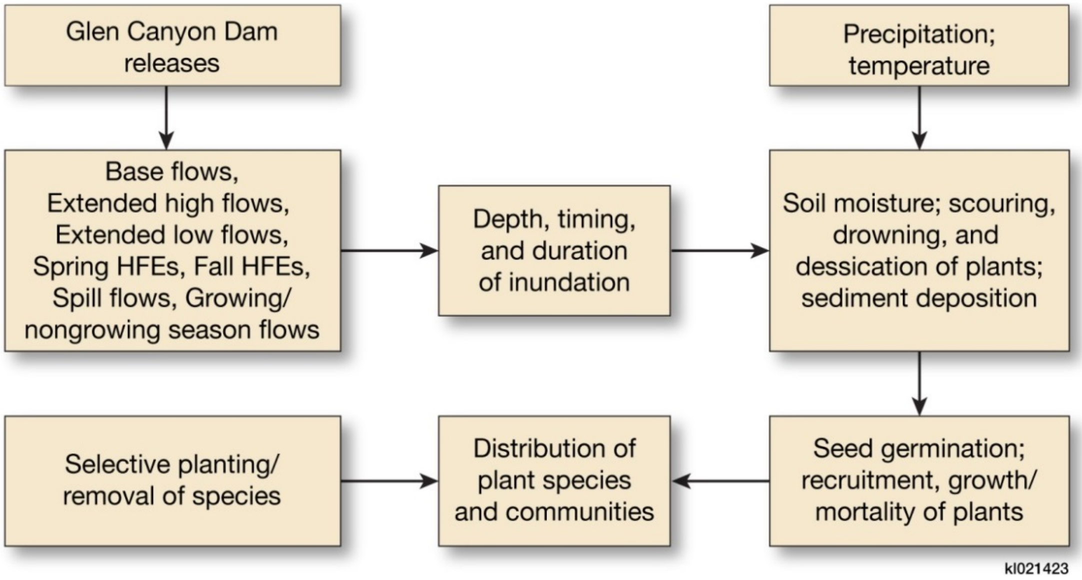

FIGURE 4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon Dam

4.6.2.1 Impacts on Old High Water Zone Vegetation

The riparian vegetation that became established along the Colorado River channel margin in response to annual peak flows prior to the construction of Glen Canyon Dam is located at high flow stage elevations (above 60,000 cfs, but primarily from about 100,000 to approximately 200,000 cfs), well above the level of current dam operations. The Old High Water Zone plant communities are described in Section 3.6. Mortality of riparian plants within this zone, along with a lack of seedling establishment for some species, such as mesquite and hackberry, have been occurring for decades, because of a lack of sufficiently high flows and nutrient-rich sediment (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Dam operations, other than HFEs, do not exceed 31,500 cfs flows (although all alternatives have a normal maximum operating flow of 25,000 cfs), and HFEs do not exceed 45,000 cfs. None of the alternatives considered would include flows sufficient to maintain these pre-dam plant communities. HFEs could provide soil moisture to the deep root systems of some Old High Water Zone plants that are at the lower edge, close to the New High Water Zone, providing occasional soil moisture. Studies indicate that dam releases can affect water availability to plants at elevations up to approximately 15,000 cfs above flow levels (Melis et al. 2006; Ralston 2005). Alternatives with more frequent spring HFEs, such as Alternatives C, D, E, F, and G, may result in higher survival rates of plants at lower elevations of the Old High Water Zone than Alternative A due to increased moisture within the root zone. The differences between alternatives are expected to be minor in terms of effects on the lower margin of the Old High Water Zone. Several alternatives include extended-duration HFEs (longer than 96 hr; e.g., up to 250 hr under Alternative D); however, because these HFEs only occur during the fall (the non-growing season), their contribution to higher survival rates would likely be limited.

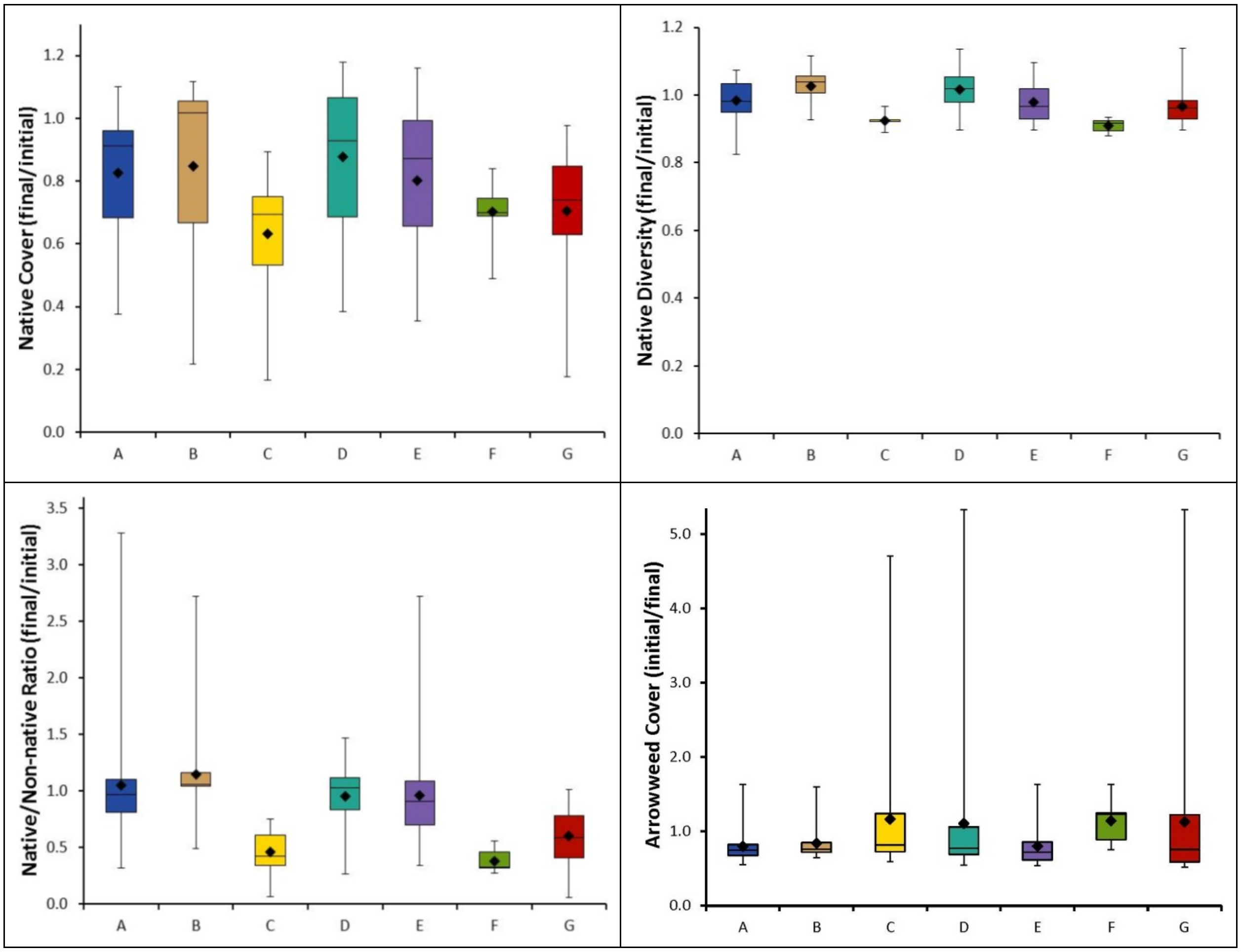

FIGURE 4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as Predicted by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change over the LTEMP period; values >1 indicate an improvement relative to current conditions; values <1 indicate a decline relative to current conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Because of generally continued low soil moisture and lack of recruitment opportunities under all alternatives, the upper margins of this zone would be expected to continue moving downslope, with a continued narrowing of the riparian zones. Desert species occurring on the pre-dam flood terraces and windblown sand deposits above the Old High Water Zone would increasingly establish within this zone, depending on climate and precipitation. Overall, all alternatives would result in a decline in upper margins Old High Water Zone plant communities, because none feature regular flows >45,000 cfs. The likelihood of these very high flows, which would occur only under emergency dam operations, is considered very low, and would be the same for all alternatives. Therefore, the narrowing of the Old High Water Zone is outside the scope of the LTEMP impact analysis.

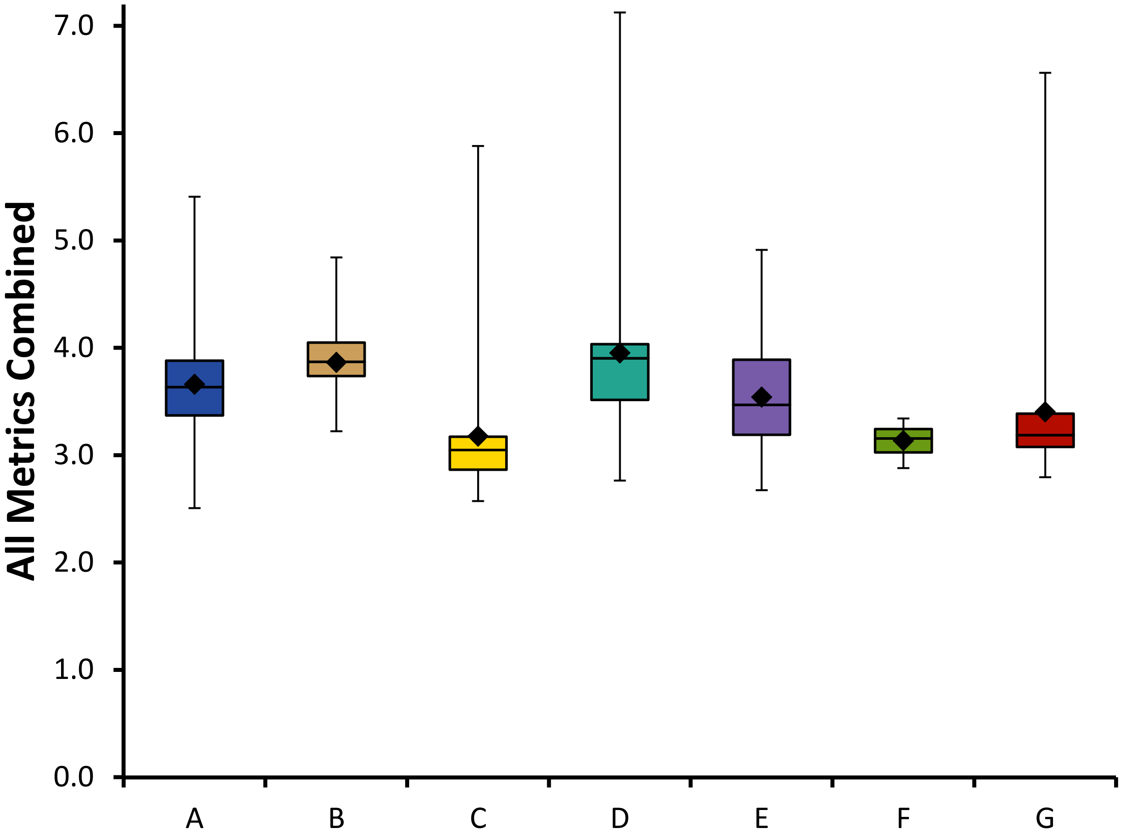

FIGURE 4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as Predicted by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the end of the LTEMP period relative to the amount at the beginning; values of 4 indicate no change over the LTEMP period; values >4 indicate an improvement relative to current conditions; values <4 indicate a decline relative to current conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.6.2.2 Impacts on New High Water Zone

Plant community types that have developed in the New High Water Zone in response to Glen Canyon Dam operations include cottonwood-willow and mesquite communities, both native species-dominated community types, as well as tamarisk (a nonnative species-dominated community type) and arrowweed (an invasive native species-dominated community type) (Ralston et al. 2014). Two native species-dominated wetland community types, marsh and shrub wetland, that occur in the Fluctuation Zone are discussed in Section 4.6.2.3. Transitions between plant community types, or to bare sand, are driven by specific flow events that vary among the alternatives. Spring HFEs, fall HFEs, spill flows, extended low flows, extended high flows, and seasons without extended high or low flows occurring during the growing or non-growing season result in changes in the distribution and cover of New High Water Zone plant communities.

HFEs alone do not result in transitions but generally act in combination with other flow events. Colorado River flows affect the composition, structure, and distribution of riparian vegetation communities through the effects of drowning, scouring, sediment deposition, desiccation, and maintaining alluvial groundwater levels (Sankey, Ralston et al. 2015; Ralston et al. 2014; Ralston 2005, 2010, 2012; Kennedy and Ralston 2011; Kearsley et al. 2006; Porter 2002; Kearsley and Ayers 1999; Stevens et al. 1995). HFEs result in sediment deposition and increased water availability at higher stage elevations but little scouring, extended high flows drown and scour plants and maintain ground-water levels, while extended low flows can desiccate plants, especially seedlings, while providing a consistent water supply to plants at very low stage elevations. Transitions and initiating flows are presented in Table G-3, in Appendix G.

Flows that result in increases or decreases in cottonwood-willow and mesquite communities are given in Table 4.6-4. Alternatives with greater occurrence of transitions from bare sand to native plant communities and/or maintenance of those communities (i.e., a lack of transitions to bare sand) would result in greater native community cover. However, repeated seasons of extended high flows, extended high flows above 50,000 cfs, or spill flows transition native communities to bare sand through the processes of drowning, scouring, and burial (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). All of the alternatives would result in a decrease in native plant community cover (see discussions below under individual alternatives). However, annual hydrology has a greater effect on the change in native community types than the operational characteristics of the alternatives.

Flows that result in increases or decreases in tamarisk are given in Table 4.6-4. The overall cover of tamarisk-dominated communities would be expected to increase under Alternatives C, F, and G, each of which are expected to produce frequent transitions to tamarisk communities, in large part because they frequently have extended high flows, extended low flows, and spring HFEs. This combination of flows encourages transitions to tamarisk because tamarisk increases when high flows coincide with seed release during spring and early summer, followed by lower flows, all of which results in establishment of seedlings above the elevation of subsequent floods (Mortenson et al. 2012; Stevens and Siemion 2012). Also, under these alternatives, various community types frequently shift to bare sand, which then shifts to tamarisk. Each of these alternatives has more extended low flows and more spring HFEs than the other alternatives. The overall cover of the tamarisk is expected to decrease under Alternatives A, B, D, and E. Each of these alternatives has frequent extended high flows, which result in consecutive seasons and consecutive years of extended high flows. Two or more years of extended high flows are required for tamarisk to be removed by drowning, leaving a bare sand lower reattachment bar, or two consecutive seasons (growing and non-growing) on a lower separation bar (Kearsley and Ayers 1999; Stevens and Waring 1986a).

The presence of the tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil (*Coniatus* spp.) along much of the Colorado River below Glen Canyon Dam has resulted in defoliation of tamarisk in many areas, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Considerable uncertainty still exists regarding the long-term effects of the beetle and weevil on the tamarisk population below the dam and subsequent effects on ecosystem dynamics within the New High Water Zone. The replacement of tamarisk by other species and the timing of replacement would be affected by flow characteristics. Tamarisk may

TABLE 4.6-4 Transitions between Riparian Community Types and the Flows That Initiate Transitions

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Increase New High Water Zone Natives			
Bare sand	Cottonwood-willow	Lower separation bar	Growing season and non-growing season without extended high or low flows the same year (7 yr; slowed by non-growing-season extended high flow with growing season without extended high or low flow the same year) (Waring 1995; Ralston et al. 2008).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow next growing season (Ralston 2010).
Tamarisk	Mesquite	Upper bars/channel margin; lower channel margin	Spring HFE with growing season without extended high or low flow or extended high flow the same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
Transitions That Decrease New High Water Zone Natives			
Cottonwood-willow	Bare sand	Lower separation bar	Spill flow[a]; non-growing-season extended high plus growing-season extended high same year; or growing-season extended high followed by non-growing-season extended high the next year.(Stevens and Waring 1986a)
Cottonwood-willow	Bare sand	Lower channel margin	Spill flow[a]; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Mesquite	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow[a] or any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Transitions That Increase Wetland			
Bare sand	Marsh	Lower reattachment bar	Growing season without extended high or low flow (2 yr; slowed by growing season with extended high flow) (Stevens et al. 1995; Kearsley and Ayers 1999; Ralston 2010).
Bare sand	Shrub wetland	Lower channel margin	Non-growing season without extended high or low flow plus growing season without extended high or low flow (4 yr, can be slowed by growing season with extended low flow or HFE; extended high flow starts process over) (Stevens and Waring 1986a; Porter 2002).

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Decrease Wetland			
Marsh, shrub wetland	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012).
Marsh, shrub wetland	Bare sand	Lower reattachment bar	Spill flow[a]; any season with extended high flow followed by an extended high flow next growing season; growing season with extended high flow followed by a non-growing season with extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Shrub wetland	Bare sand	Lower channel margin	Any season with extended high flow over 25,000 cfs (Stevens and Waring 1986a).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow the next growing season (Ralston 2010).
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
Transitions That Increase Tamarisk			
Marsh, shrub wetland, arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002).
Bare sand	Tamarisk	Lower separation bar; lower channel margin	Non-growing season with extended high flow, or spring HFE plus growing season with extended low flow the same year (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012; Sher et al. 2000).
Bare sand	Tamarisk	Lower reattachment bar	Growing season with extended low flow (Stevens and Waring 1986a; Porter 2002; Sher et al. 2000).
Bare sand	Tamarisk	Upper bar/channel margin	Spring HFE plus growing season with extended high flow the same year (Sher et al. 2000; Mortenson et al. 2012).
Transitions That Decrease Tamarisk			
Tamarisk	Bare sand	Lower separation bar	Spill flow[a]; non-growing-season extended high flow plus growing-season extended high flow same year; or growing-season extended high flow followed by non-growing-season extended high flow the next year (Stevens and Waring 1986a).

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Decrease Tamarisk (Cont.)			
Tamarisk	Bare sand	Lower reattachment bar	Spill flow[a]; 4 consecutive seasons of non-growing-season extended high flow plus growing-season extended high flow; growing-season extended high flow (4 consecutive years) (Stevens and Waring 1986a; Kearsley and Ayers 1999).
Tamarisk	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow[a]; any season extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Tamarisk	Mesquite	Lower channel margin; upper bar/channel margin	Spring HFE with growing season without extended high or low flow or extended high same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
Transitions That Increase Arrowweed			
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
Bare sand	Arrowweed	Upper bar/channel margin	Non-growing season with extended low flow, or seasons without extended high or low flow, or non-growing season with extended high flow, plus growing season with extended low flow, or seasons without extended high or low flow, or growing season with extended high flow; same year (3–6 yr, extended high flows increase the rate, slowed by fall HFE) (Waring 1995).
Transitions That Decrease Arrowweed			
Arrowweed	Bare sand	Lower reattachment bar	Spill flow[a]; any season with extended high flow followed by an extended high flow the next growing season; growing season with extended high flow followed by a non-growing season extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Arrowweed	Bare sand	Upper bar/channel margin	Spill flow[a]; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002).

[a] Spill flows are releases through the spillway and are non-discretionary emergency actions that do not vary among alternatives.

Source: Ralston et al. (2014).

not establish as readily on bare sand substrates, or transition from other community types, as in the past (and described above) if seed sources are reduced. Additionally, tamarisk communities may become less stable and more easily removed by high flows than in the past. Therefore, increases in tamarisk that would be expected to result under Alternatives C, F, and G, may be less than expected, and decreases of tamarisk under Alternatives A, B, D, and E may be greater than expected.

Flows that would result in increases or decreases in arrowweed are given in Table 4.6-4. The overall cover of the arrowweed community type would be expected to increase under Alternatives A, B, and E; under these alternatives, bare sand would transition to arrowweed rather than tamarisk because there are few spring HFEs and/or few growing-season extended high flows, both of which promote the establishment of tamarisk on bare sand, and, except in Alternative B, arrowweed would transition from marsh because of growing-season extended low flows (Porter 2002). Once established, arrowweed would tend to remain for many years under these alternatives. HFEs alone are not effective at reducing arrowweed as burial typically results in resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth occurs (Ralston 2012). Arrowweed would decrease under Alternatives C, D, F, and G, usually by transitioning to bare sand with repeated extended high flows (Ralston 2010; Stevens and Waring 1986a), but often by transitioning to tamarisk under Alternatives C, F, and G. The hydrology of the river (e.g., wet years vs. dry years), however, has a greater effect on the change in arrowweed than the characteristics of the alternatives. Drier years tend to have fewer extended high flows resulting in more arrowweed due to fewer transitions to bare sand or tamarisk.

Given that under all alternatives vegetation condition degrades to some degree, experimental riparian vegetation treatments are planned under all alternatives except for Alternative A. These activities are expected to modify the cover and distribution of plant communities along the Colorado River and improve the vegetation conditions. These vegetation treatments include removal of nonnative plants, revegetation with native species, clearing of undesirable plants from campsites, and management of vegetation to assist with cultural site protection. All vegetation treatments would occur only within the Colorado River Ecosystem, which could be influenced by dam operations. Native species, such as Goodding's willow and cottonwood, would be planted to increase and maintain populations of these species. Native plant materials would be developed for replanting through partnerships and use of regional greenhouses; this would include the collection of propagules (seeds, cuttings, poles, or whole plants) from riparian areas in both the river corridor and side canyons. Removal of nonnative plants would include mechanical means (e.g., cutting), smothering, spot burning, or use of herbicides. Monitoring of riparian areas subsequent to the implementation of any alternative would direct the specific locations and degree of implementation of non-flow actions. Nonnative species targeted for removal would be those affected by dam operations that are considered the greatest threat to park resources and having a high potential for successful control (Table 4.6-5). Control and removal of the native arrowweed would be conducted where this species is encroaching on campsites where camping area has been lost. In addition to ongoing removal of selected nonnative plant species in the river corridor, targeted vegetation treatment at priority sites or sub-reaches would include systematic removal of tamarisk and replanting and seeding of natives. The acreage that would be targeted for priority treatment would vary by alternative, depending on expected changes in riparian community types. An estimate of the change in

TABLE 4.6-5 Priority Nonnative Species Identified for Control within the Colorado River Corridor

Scientific Name	Common Name
Rhaponticum repens	Russian knapweed
Alhagi maurorum	camelthorn
Brassica tournefortii	Sahara mustard
Convolvulus arvensis	black bindweed
Cortaderia selloana	Pampas grass
Echinochloa crus-galli	barnyardgrass
Eragrostis curvula	weeping love grass
Elaeagnus angustifolia	Russian olive
Lepidium latifolium	perennial pepperweed
Malcolmia africana	African mustard
Phoenix dactylifera	date palm
Saccharum ravennae	Ravenna grass
Salsola tragus	Russian thistle
Schedonorus arundinaceus	tall fescue
Sisymbrium altissimum	tumble mustard
Sisymbrium irio	London rocket
Solanum elaeagnifolium	silverleaf nightshade
Sonchus asper	spiny sowthistle
Sonchus oleraceus	common sowthistle
Tamarix aphylla	athel
Tamarix spp.	salt cedar
Tribulus terrestris	puncture vine
Ulmus pumila	Siberian elm

acreage of tamarisk or arrowweed under each of the alternatives is given in Section 4.6.3. Alternatives that result in greater increases in these species would be expected to also result in a greater extent of targeted vegetation treatment. Therefore, differences among alternatives in changes of tamarisk or arrowweed may be somewhat less than indicated by flow effects alone. Vegetation treatments would be expected to occur at limited locations, and these areas would likely only comprise a small proportion of the riparian area below Glen Canyon Dam.

4.6.2.3 Wetlands

Wet marsh communities of flood-tolerant herbaceous species that occur on low elevation areas of reattachment bars within the Fluctuation Zone (i.e., the range of normal operational fluctuations between the elevations of 5,000 and 25,000 cfs flows) have developed in response to frequent inundation (daily for at least part of the year) (Stevens et al. 1995; Ralston 2005, 2010). These marsh communities (with common reed and cattail the dominant species) occur on fine-grained silty loam soils in low-velocity environments on lower areas of eddy complex sandbars, which, although easily scoured by high flows, can redevelop quickly. Clonal wetland species such as cattail, common reed, and willow are adapted to burial and regrowth and recover following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Native flood-adapted species increase in low-elevation areas following growing-season steady high flows, potentially by vegetative reproduction (Porter 2002; Ralston 2011). Shrub wetland communities (with coyote willow, seep willow, and horsetail the dominant species) occur on sandy soils of reattachment bars and channel margins, below the 25,000 cfs stage, that are less frequently inundated. Mortality of horsetail occurs at higher elevations above the water table during growing-season low steady flows (Porter 2002). Large daily fluctuations increase the area of saturated soil, and thus the sandbar area available for wetland species establishment (Stevens et al. 1995; Carothers and Aitchison 1976; Kearsley et al. 2006). The reduction of daily fluctuations may increase the establishment of wet marsh species at lower elevations and promote the transition of higher elevation marshes to woody phreatophyte species such as tamarisk or arrowweed (Stevens et al. 1995). Periodic flooding and drying tends to increase diversity and productivity in wetland communities (Reclamation 2011b; Stevens et al. 1995). Although low-elevation plants in marshes in Marble Canyon and Grand Canyon, such as cattail, common reed, and willow, may become buried with coarse sediment, recovery generally occurs within 6–8 months (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Low steady flows can cause some wetland patches to dry out, resulting in considerable mortality (Porter 2002). Sustained high releases reduce wetland vegetation cover to less than 20% on lower reattachment bars, allowing tamarisk to occupy open space, if sustained low releases occur in the next growing season (Ralston et al. 2014; Sher et al. 2000). Extended high flows typically scour herbaceous vegetation; however, most woody plants often remain (Ralston et al. 2014). Thus, extended high flows followed by extended low flows in the following growing season result in a transition from shrub wetland to a cottonwood-willow community on channel margins because of an increase in overstory cover and a decrease in herbaceous understory plants (Ralston 2010).

Flows that result in increases or decreases in marsh or shrub wetland communities are given in Table 4.6-4. A transition from marsh to shrub wetland occurs on lower reattachment bars with 4 years of consecutive seasons of low fluctuating flows or non-growing-season sustained low flows (Ralston et al. 2014; Stevens et al. 1995). A fall or spring HFE delays the transition for 1 year; however, an extended high flow before the transition removes the established plants (Ralston et al. 2014).

Wetland communities generally transition only from bare sand or other wetlands (Ralston et al. 2014; Stevens et al 1995); they can transition back to bare sand or to arrowweed, tamarisk, or cottonwood-willow communities (Mortenson et al 2012; Ralston 2010; Porter 2002; Sher et al. 2000; Kearsley and Ayers 1999; Stevens and Waring 1986a). A greater occurrence of transitions from bare sand to wetlands and/or maintenance of wetlands (lack of transitions to other community types) would result in greater wetland cover. Alternatives that include frequent extended low flows, such as annually for Alternative F, or extended high flows followed by extended low flows tend to result in transitions of wetlands to other plant community types. All of the alternatives are expected to result in a decrease in wetland cover, with particularly large decreases for Alternative F. The relative change in cover (final based on model results/initial) of wetland community types is presented in Figure 4.6-4.

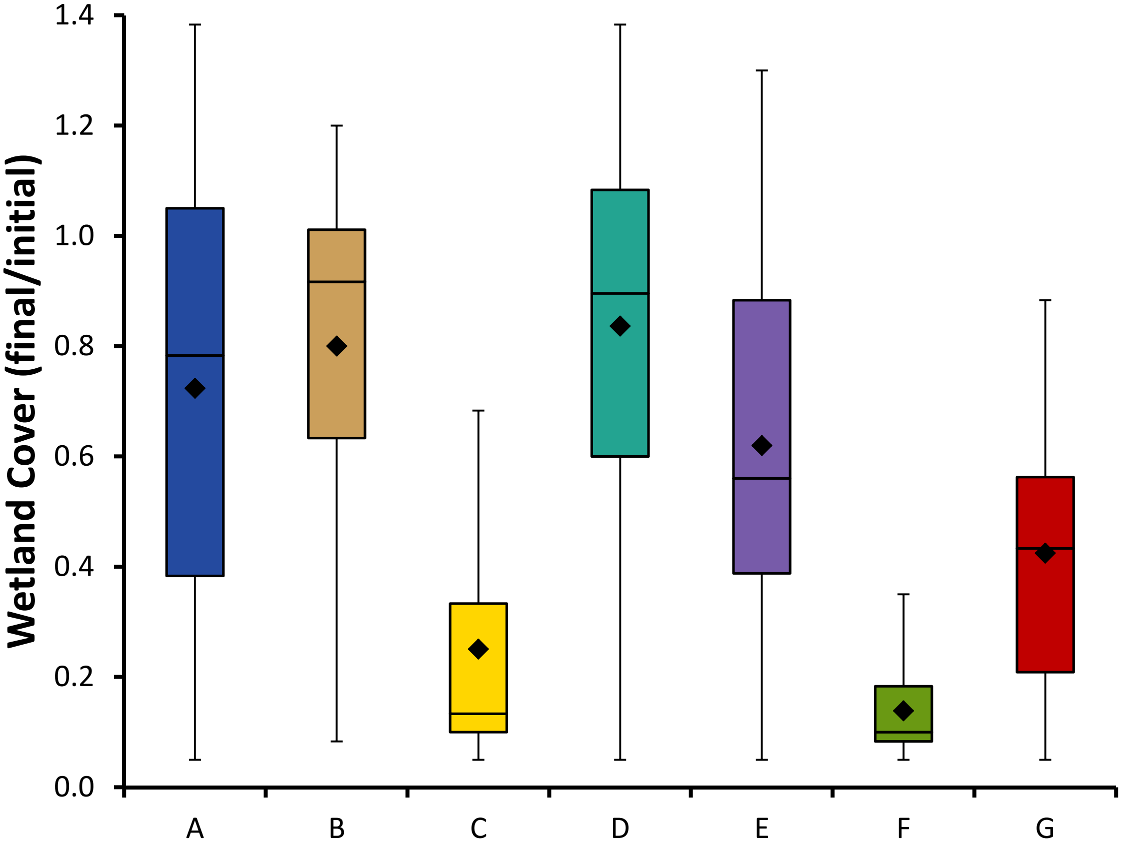

FIGURE 4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a Vegetation Model (Metric represents the proportion of the estimated amount of wetland vegetation types at the end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change over the LTEMP period; values >1 indicate an increase; values <1 indicate a decrease. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.6.2.4 Special Status Plant Species

Impacts on special status plant species that are known to occur along the Colorado River from Glen Canyon Dam to Lake Mead are summarized in Table 4.6-6. Scientific names, listing status, and habitat are presented in Section 3.6, Table 3.6-2. The analyses of impacts for special status plant species is similar to the analysis for other vegetation and relies on an evaluation of impacts on the habitat associated with each species.

Species of active floodplains occur above the elevation of daily releases (25,000 cfs) but within the stage elevation of HFEs (45,000 cfs). These include Grand Canyon evening primrose (*Camissonia specuicola* ssp. *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), lobed daisy (*Erigeron lobatus*), and may include giant helleborine (*Epipactis gigantea*). These species are generally not affected by HFEs because of their short duration, however, Alternatives C, D, and G include extended-duration HFEs (up to 250 hr under

TABLE 4.6-6 Summary of Impacts of LTEMP Alternatives on Special Status Plant Species

Species	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Species of active floodplains (25,000–45,000 cfs) Grand Canyon evening primrose (*Camissonia specuicola* ssp. *Hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), lobed daisy (*Erigeron lobatus*), giant helleborine (*Epipactis gigantea*)	No impact from current operations; located above the level of daily operations.	Same as Alternative A.	Compared to Alternative A, small potential for temporary impacts from extended-duration HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.	Compared to Alternative A, small potential for temporary impacts from extended-duration HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.	Same as Alternative A.	Compared to Alternative A, small potential for temporary impacts from high frequency of HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.	Small potential for temporary impacts from extended-duration HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.
Species of the Lake Mead shoreline sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), Las Vegas bear poppy (*Arctomecon californica*)	No impact on species from current operations.	No impact.	No impact.	No impact.	No impact.	Minor increase in April–June in Lake Mead shoreline elevation inundating habitat (highest impact of alternatives).	Similar to Alternative A.
Species of inactive floodplains (>45,000 cfs) Marble Canyon spurge (*Euphorbia aaron-rossii*), hop-tree (*Ptelea trifoliata*)	No impact from current operations; located above dam operational effects.	Same as Alternative A.	Compared to Alternative A, small potential for benefit from spring HFEs.	Compared to Alternative A, small potential for benefit from spring HFEs.	Compared to Alternative A, small potential for benefit from spring HFEs.	Compared to Alternative A, small potential for benefit from annual spring HFEs (lowest impact of alternatives).	Same as Alternative A.

TABLE 4.6-6 (Cont.)

Species	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Species of fluctuation zones and wetlands satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), American bugleweed (*Lycopus americanus*)	No change from current conditions; potential impact resulting from continuing loss (28%, 1.3 ac) of wetland habitat.	Compared to Alternative A, less impact resulting because less wetland habitat would be lost (20%, 0.9 ac).	Compared to Alternative A, greater impact resulting from 75% (3.4 ac) decrease in habitat.	Compared to Alternative A, less impact because less wetland habitat would be lost (16%, 0.8 ac) decrease in habitat (lowest impact of alternatives).	Compared to Alternative A, greater impact resulting from 38% (1.7 ac) decrease in habitat.	Compared to Alternative A, greater impact resulting from 86% (4.0 ac) decrease in habitat (highest impact of alternatives).	Compared to Alternative A, greater impact resulting from from 58% (2.6 ac) decrease in habitat.

Alternative D and 336 hr under Alternative G), while Alternative F has annual spring HFEs. A slightly increased potential for burial from these HFEs could result in a temporary increase in impacts on special status species because of their small populations. These impacts of inundation and burial are expected to be temporary because the Grand Canyon evening primrose, lobed daisy, and giant helleborine are floodplain species adapted to flooding disturbance. The main populations of the primrose, helleborine, and daisy are in springs up tributaries away from the river, and the Mohave prickly pear is also found in sandy flats above the 45,000-cfs stage elevation. These areas would be unaffected by HFEs, and could serve as sources for recolonization of floodplain habitats.

Species of the Lake Mead shoreline include sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*). These species are generally not affected by fluctuations in the Lake Mead surface elevation, as under current operations. However, alternatives that raise the reservoir surface elevation, such as the minor elevation increase in April–June under Alternative F (see Figure 4.2-4), inundate the shoreline habitat for these species, potentially resulting in drowning of individuals below the highest shoreline elevation. These effects are expected to be offset by increases in germination, growth, and reproduction of individuals above that level, which would benefit from increases in soil moisture.

Species of inactive floodplains, Marble Canyon spurge (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*), occur above the stage elevation of HFEs (45,000 cfs) but below the elevation of the desert scrub community. These species are not directly affected by dam operations; however, alternatives with more frequent spring HFEs, such as Alternatives C, D, E, F, and G, potentially provide a slight benefit to these species through frequent increases in soil moisture.

Species of the fluctuation zone are inundated by daily operations and are typically associated with wetland communities. These include satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*). The loss of wetland community cover under all alternatives would result in a loss of habitat for these species; Alternatives B and D would result in a decrease impacts on these species compared to Alternative A, while Alternatives C, E, F, and G would result in an increase in impacts. Alternative D would have the least impact of any alternative; Alternative F would have the highest impact.

4.6.3 Alternative-Specific Impacts

The resources addressed in this section include the riparian plant communities of the New High Water Zone and the Fluctuation Zone. The mechanisms underlying New High Water Zone vegetation changes associated with hydrologic events, and the associated research supporting those mechanisms, are described in Section 4.6.2. Details of the model and calculation of the performance metrics can be found in Appendix G. Although the model is not spatially explicit and, therefore, cannot predict changes to plant communities on individual sandbars and channel margin depositional features, acreage changes that are calculated from the currently mapped extent of each of the modeled community types are presented in this section, based on the modeled increase or decrease in each type.

As noted in Section 4.6.2.2, experimental vegetation treatments would also be implemented that would result in modifications to the riparian vegetation communities in the New High Water Zone. Although these areas may be a relatively small proportion of the riparian area below Glen Canyon Dam, implementation of non-flow actions would result in the reduction of nonnative species populations, including tamarisk, and increases in native species populations on sandbars and channel margin areas. Consequently, the native/nonnative ratios (as well as changes in tamarisk) identified for each alternative in this section would likely be higher with the implementation of non-flow actions under those alternatives. Similarly, the arrowweed metric presented for each alternative would likely be higher with the implementation of non-flow actions under those alternatives.

4.6.3.1 Alternative A (No Action Alternative)

Under Alternative A (the No Action Alternative), base operations (i.e., the intervening flows that occur between HFEs or other experimental flow manipulations) are MLFF, the flow regime that was put in place by the 1996 ROD (Reclamation 1996) for the 1995 Glen Canyon EIS (Reclamation 1995). This alternative includes sediment-triggered spring and fall HFEs through 2020 (no spring HFEs until 2016) that would be implemented according to the HFE protocol developed and evaluated in the HFE EA (Reclamation 2011b). Alternative A has higher monthly volumes in the high electricity demand months of December, January, July, and August than in other months. This alternative has fewer spring and fall HFEs than other alternatives, occasional extended low flows, and more frequent extended high flows than most other alternatives, the latter being particularly frequent in the growing season.

Frequent extended high flows would result in a decrease in the native community types including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and Waring 1986a). Repeated seasons of extended high flows have been observed to cause the transition of native communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). This is supported by modeling results which indicate a 17% (55.2 ac) overall decrease in native plant community cover and 28% (1.3 ac) decrease in wetland community cover.

The frequent extended high flows and few extended low flows (along with few spring HFEs) would tend to remove tamarisk and would be accompanied by a reduced level of establishment of tamarisk (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000; Kearsley and Ayers 1999; Stevens and Waring 1986a), resulting in an overall decrease in tamarisk-dominated communities. Because the decrease in tamarisk modeled (58.4 ac) exceeds the decrease in native community types (55.2 ac), the ratio of native to nonnative community types would be expected to increase by about 5% under Alternative A.

Frequent extended high flows, few spring HFEs, and occasional fall HFEs would also promote the establishment of arrowweed on upper elevation areas (Waring 1995). Based on results of modeling, Alternative A is expected to result in a 25% (44.5 ac) increase in the arrowweed community type.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3.

In summary, Alternative A would result in beneficial changes associated with an increase in the ratio of native to nonnative community types as a result of a decrease in tamarisk cover (5% increase in ratio, 58.4 ac decrease in tamarisk). These benefits could be greater than anticipated, depending on the effects of the tamarisk leaf beetle in the area, but the lack of experimental vegetation treatments included under other alternatives would not provide benefits. However, Alternative A is also expected to result in adverse effects associated with a decrease in native cover (17% overall decrease in native plant community cover; 28% decrease in wetland community cover) and native diversity (2% decrease in native diversity over the LTEMP period due to decrease in wetland communities), and an increase in arrowweed cover (25% increase in cover). Several special status species could be impacted as a result of the continuing decrease in wetland community cover (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing. It is expected that Alternative A would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.2 Alternative B

Alternative B includes spring and fall HFEs (the number of HFEs not to exceed one every other year), with few spring HFEs, similar to Alternative A, but slightly more fall HFEs compared to Alternative A. TMFs are also included in this alternative. This alternative has the same monthly pattern in release volume as the Alternative A; however, due to the large daily fluctuations, Alterative B has no extended low flows and has frequent extended high flows, at a slightly greater frequency compared to Alternative A.

Frequent extended high flows would result in a decrease in native community types including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and Waring 1986a); however, the decrease, including wetland decrease, is less (statistically significant) than under Alternative A. Repeated seasons of extended high flows transition native communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). This is supported by modeling results which indicate a 15% (48.3 ac) overall decrease in native plant community cover and 20% (0.9 ac) decrease in wetland community cover. Although the amount of native cover would be expected to decrease under this alternative, the diversity of native community types is expected to increase 3%. This alternative would result in a greater area of wet marsh than Alternative A primarily because of a lack of extended low flows that would contribute to a loss of marsh (Sher et al. 2000; Porter 2002).

The frequent extended high flows would result in a tendency to remove tamarisk through repeated effects (consecutive seasons or years) of drowning, limited growth, and depleted energy reserves (Kearsley and Ayers 1999; Stevens and Waring 1986a), and a lack of extended low flows (along with few spring HFEs) would result in a reduced level of tamarisk seedling establishment (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000), resulting in an overall decrease in tamarisk-dominated communities, with there being more of a decrease than under Alternative A. Because of the large decrease in tamarisk-dominated communities modeled (71.4 ac) and smaller decrease in native cover (48.3 ac), the ratio of native to nonnative community types under this alternative would increase 15% and is significantly higher (statistically significant) than that for Alternative A.

Frequent extended high flows, few spring HFEs, and more fall HFEs would also promote the establishment of arrowweed on upper elevation areas (Waring 1995). Based on results of modeling, Alternative B is expected to result in a 19% increase (33.3 ac) in arrowweed, although at a level less than under Alternative A (however, the difference is not statistically significant).

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. One experimental element, hydropower improvement flows, results in a considerable increase in the frequency of extended high flows, resulting in a greater decrease in native community types (150.1 ac) and tamarisk (107.0 ac) and a slightly greater increase in arrowweed (41.9 ac) (although not a statistically significant difference).

In summary, Alternative B would result in beneficial changes associated with an increase in native diversity (3% increase over the LTEMP period, a higher diversity than Alternative A), and an increase in the ratio of native to nonnative community types as a result of a decrease in tamarisk cover (a 15% increase in ratio, a higher ratio than under Alternative A; 71.4 ac decrease in tamarisk, a greater decrease than under Alternative A). These benefits could be greater than anticipated depending on the effects of the tamarisk leaf beetle in the area and the non-flow vegetation treatment restoration experiments. However, Alternative B is also expected to result in adverse effects associated with a decrease in native cover (15% overall decrease in native plant community cover, 20% decrease in wetland community cover; both less of a decrease than under Alternative A) and an increase in arrowweed cover (19% increase in cover, less than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover, although the decreases would be less than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing. Although the vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative B would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk. Alternative B would result in higher fluctuation flows, although flows prior to the 1996 ROD (Reclamation 1996) had a much greater daily range than Alternative B (28,500–30,500 cfs; Reclamation 1995). The shift from those flows to MLFF resulted in a general reduction of marsh habitat and an increase in tamarisk and arrowweed, particularly in the upper elevations of the former Fluctuation Zone (Ralston 2005). An increase in fluctuations would not necessarily reverse those trends but would be expected to result in greater marsh area (Stevens et al. 1995) and potentially less tamarisk and arrowweed than under MLFF of Alternative A. These increases would not be realized under experimental hydropower improvement flows.

4.6.3.3 Alternative C

Alternative C includes spring and fall HFEs that could be triggered by Paria River sediment inputs in all years during the LTEMP period and proactive spring HFEs (24 hr, 45,000 cfs HFE) that would be tested in April, May, or June in high-volume years. Lower fluctuation levels conserve more sediment, and therefore result in more triggered HFEs. As a result, this alternative has a far greater frequency of fall and spring HFEs compared to Alternatives A and B (see Section 4.2). TMFs are also included in this alternative. Alternative C has highest monthly release volumes in December, January, and July, and lower volumes from August through November; volumes in February through June would be proportional to power contract delivery rates. This alternative has a higher frequency of extended low flows compared to Alternative A and far fewer growing or non-growing seasons without extended high or low flows. Although Alternative C generally has fewer growing-season extended high flows than Alternative A, it has a slightly greater frequency of non-growing-season extended high flows.

Repeated high flows have been observed to shift vegetation communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). A greater frequency of HFEs, very few seasons without extended high or low flows, and far more extended low flows would result in a lack of establishment of native community types; consequently, native community types including wetlands decrease under this alternative (Ralston et al. 2008; Waring 1995; Anderson and Ruffner 1987), with the decrease being greater (statistically significant) than that under Alternative A. This alternative has the greatest decrease in native cover of all the alternatives and the second greatest decrease in wetlands (only Alternative F is greater). Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002), and the establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This is supported by modeling results which indicate a 37% (117.7 ac) overall decrease in native plant community cover and 75% (3.4 ac) decrease in wetland community cover. The diversity of native community types decreases 8% under this alternative is lower than that under Alternative A, primarily due to the large decreases in the wetland community types.

Growing-season extended low flows can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002) and promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Spring HFEs can also contribute to tamarisk establishment on bare sand (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012; Sher et al. 2000). Consequently, tamarisk-dominated communities would be expected to increase considerably under Alternative C (104.0 ac, only Alternative F has a greater increase). Because of the large decrease in native community types (117.7 ac), the ratio of native to nonnative community types under this alternative decreases 54% and is significantly lower (statistically significant) than under Alternative A, and is the largest difference between the two alternatives.

Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999; Ralston 2010), while extended low flows contribute to tamarisk replacing arrowweed (Sher et al. 2000; Stevens and Waring 1986a; Porter 2002). Arrowweed would therefore decrease 14 % (25.1 ac) based on results of modeling, under this alternative, a statistically significant difference from the increase under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows and TMFs. Low summer flows result in a slight increase in extended low flows, as well as a slight increase in extended high flows (due to redistribution of water during other months). However, the effects on riparian vegetation are small and often undetectable in the model results, since low summer flows are relatively infrequent, and do not have a large effect relative to other components of the alternatives. TMFs, combined with proactive spring HFEs, result in twice the tamarisk increase (more bare sand becoming tamarisk rather than arrowweed) and a decrease in arrowweed.

In summary, Alternative C would result in a beneficial change associated with a decrease in arrowweed cover (14% decrease in cover, less cover than the increase under Alternative A). This benefit could be greater than anticipated depending on the effects of the vegetation treatments. However, Alternative C is also expected to result in adverse effects associated with a decrease in native cover (37% overall decrease in native plant community cover, 75% decrease in wetland community cover; both greater decreases than under Alternative A), decrease in native diversity (8% decrease, lower diversity than under Alternative A), and decrease in the ratio of native to nonnative community types (54% decrease in ratio, a lower ratio than under Alternative A; 104 ac increase in tamarisk, greater tamarisk cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover; this is expected to be a larger effect than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur as a result of HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. There is a small potential for impacts on active floodplain special status species. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative C would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.6.3.4 Alternative D (Preferred Alternative)[18]

This alternative includes a variety of HFE types throughout the LTEMP period including: sediment-triggered spring (March–April) and fall (October–November) HFEs; proactive spring HFEs (24 hr, 45,000 cfs) would be tested (April, May, or June) in high-volume years; no spring HFEs in the first two years; and extended-duration fall HFEs (up to 250 hr duration, up to 45,000 cfs), up to four in 20-year period. More even monthly volumes conserve more sediment and therefore result in more triggered HFEs. As a result, Alternative D has a considerably greater frequency of fall and spring HFEs compared to Alternatives A and B (Section 4.3). TMFs are also included in this alternative. This alternative has very few growing-season extended low flows, as well as slightly fewer non-growing-season extended low or high flows, due to the monthly pattern of flows as well as the amount of daily fluctuations. Alternative D has frequent growing-season extended high flows but fewer than under Alternative A. Seasons without extended low or high flows are frequent, especially non-growing seasons.

Frequent extended high flows would result in a decrease in native community types, including wetlands, although less (statistically significant) of a decrease than under Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. A greater frequency of HFEs would tend to slow establishment of shrub wetland on bare sand; extended high flows prevent establishment of this community type (Stevens and Waring 1986a; Porter 2002) and establishment of wet marsh (Stevens et al. 1995; Kearsley and Ayers 1999; Ralston 2010). However, few extended low flows during the growing season would limit the occurrence of wetland communities shifting to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002). This is supported by modeling results, which indicate a 12% (39.5 ac) overall decrease in native plant community cover and 16% (0.8 ac) decrease in wetland community cover. The diversity of native community types, a 2% increase, is significantly greater (statistically significant) under this alternative than under Alternative A because of a greater degree of evenness in native community types, as this alternative would result in a greater area of wet marsh than under Alternative A, which has more frequent extended high flows.

Repeated extended high flows, as occur under this alternative, can remove tamarisk (Stevens and Waring 1986a; Kearsley and Ayers 1999), resulting in a decrease in tamarisk-dominated communities, although less of a decrease than under Alternative A. The low number of growing-season extended low flows would limit tamarisk establishment (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). However, spring HFEs and growing-season extended high flows can promote the establishment of tamarisk (Sher et al. 2000; Mortenson et al. 2012). Because the decrease in native community types is greater than the decrease in tamarisk (22.4 ac) based on results of modeling, the ratio of native to nonnative community types under this alternative decreases and is lower than under Alternative A (the difference is statistically significant).

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[18] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on vegetation.

Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999; Ralston 2010). The establishment of arrowweed on upper elevation areas is slowed by fall HFEs (Waring 1995). In addition, the low number of extended low flows during the growing season would limit the occurrence of wetland communities shifting to arrowweed (Porter 2002). Based on results of modeling arrowweed would therefore decrease 10% (17.1 ac) under this alternative, a statistically significant difference from the increase under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2, 4.6-3, and 4.6-8. Experimental elements of this alternative include low summer flows, TMFs, and low flows for benthic invertebrate production. Low summer flows result in a slight increase in extended low flows, as well as a slight increase in extended high flows (due to redistribution of water during other months). However, the effects on riparian vegetation are small and often undetectable in the model results, since low summer flows are relatively infrequent, and do not have a large effect relative to other components of the alternatives. TMFs would result in a slightly greater reduction in native cover due to a loss of marsh to arrowweed from occasional extended low flows. Benthic invertebrate production flows do not result in any statistically significant differences in performance metrics.

In summary, Alternative D would result in a beneficial change associated with an increase in native diversity (2% increase, greater diversity than under Alternative A) and decrease in arrowweed cover (10% decrease, lower cover than under Alternative A). These benefits could be greater than anticipated depending on the effects of vegetation treatments. However, Alternative D is also expected to result in adverse effects associated with a decrease in native cover (12% overall decrease in native plant community cover, 16% decrease in wetland community cover; both decreases less than under Alternative A) and a decrease in the ratio of native to nonnative community types (5% decrease in ratio, a lower ratio than under Alternative A; 22.4 ac decrease in tamarisk, less of a decrease than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover (Figure 4.6-4), although this effect would be smaller than under Alternative A. Temporary impacts on special status floodplain species could occur as a result of HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although the non-flow vegetation treatment experiment may decrease these adverse effects to some extent, it is expected that Alternative D would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.5 Alternative E

This alternative includes sediment-triggered spring and fall HFEs implemented according to the HFE protocol (Reclamation 1995) with the exception that no spring HFEs would be implemented in first the 10 years. As a result, Alternative E has a greater frequency of HFEs, particularly fall HFEs, than Alternative A (Section 4.2). TMFs are also included in this alternative. Lower monthly water volumes would occur in August, September, and October. This alternative has frequent growing-season extended high flows but fewer than under Alternative A, and slightly more growing-season extended low flows. The non-growing season frequently has no extended high or low flows.

Frequent extended high flows would result in a decrease in the native community types including wetlands, with there being more (statistically significant) of a decrease than Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) including wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. These flows, in combination with extended low flows, can result in wetlands transitioning to tamarisk (Sher et al. 2000; Mortenson et al. 2012). The establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low or high flows or HFEs (Stevens and Waring 1986a,b; Porter 2002). Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). This is supported by modeling results which indicate a 20% (63.5 ac) overall decrease in native plant community cover and 38% (1.7 ac) decrease in wetland community cover. The diversity of native community types under this alternative would decrease and is similar to that under Alternative A.

Repeated extended high flows can remove tamarisk (Stevens and Waring 1986a; Kearsley and Ayers 1999), resulting in a decrease in tamarisk-dominated communities, although less of a decrease than under Alternative A. Because the decrease in native community types modeled (63.5 ac) is greater than the decrease in tamarisk (45.7 ac), the native to nonnative ratio under this alternative decreases 4% and is lower than under Alternative A.

Growing-season extended low flows can result in wetlands becoming replaced by arrowweed (Porter 2002), and non-growing seasons without extended high or low flows combined with growing-season extended low or extended high flows allow arrowweed to become established on bare sand (Waring 1995). Based on results of modeling arrowweed-dominated communities would be expected to increase 25% (44.0 ac) under this alternative, similar to the increase under Alternative A.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows, TMFs, and HFEs. Low summer flows result in a slight increase in extended low flows, as well as a slight increase in extended high flows (due to redistribution of water during other months). However, the effects on riparian vegetation are small and often undetectable in the model results, since low summer flows are relatively infrequent, and do not have a large effect relative to other components of the alternatives. TMFs have little effect on results of this alternative, and HFEs, when absent, result in a smaller decrease in native community types, a greater decrease in tamarisk, and a greater increase in arrowweed (arrowweed establishment on bare sand is slowed by fall HFEs; Waring 1995).

In summary, Alternative E would result in an adverse change associated with a decrease in native cover (20% overall decrease in native plant community cover, 38% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (2%, similar to Alternative A), decrease in the ratio of native to nonnative community types (4% decrease in ratio, a lower ratio than under Alternative A; 45.7 ac decrease in tamarisk, less of a decrease than under Alternative A), and an increase in arrowweed cover (25%, similar to Alternative A). These adverse effects could be less than anticipated, depending on the effects of the tamarisk leaf beetle in the area and the non-flow vegetation treatment experiment. Several special status species could be impacted as a result of the decrease in wetland community cover, and this effect would be greater than that under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur as a result of HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although the non-flow vegetation treatment experiment within the New High Water Zone (or close to the New High Water Zone where roots may be watered by HFEs) may decrease these adverse effects to some extent, it is expected that Alternative E would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.6 Alternative F

This alternative includes a much greater frequency of spring and fall HFEs than Alternative A and any other alternative (see Section 4.2). Alternative F also features higher volumes than Alternative A in April, May, and June, and lower volumes than Alternative A in other months, with low flows from July through January. This alternative has a far greater number of extended low flows than Alternative A, few seasons without extended high or low flows, and frequent growing-season extended high flows, with slightly fewer extended high flows compared to Alternative A.

Frequent extended high flows would result in a decrease in native community types, including wetlands, with there being more (statistically significant) of a decrease than Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002). A greater frequency of HFEs, very few seasons without extended high or low flows, and far more extended low flows would result in lack of establishment of native community types, including wetlands (Ralston et al. 2008; Waring 1995; Anderson and Ruffner 1987). The establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low or high flows or HFEs (Stevens and Waring 1986a; Porter 2002). Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). This is supported by modeling results which indicate a 30% (95.0 ac) overall decrease in native plant community cover and 86% (4.0 ac) decrease in wetland community cover. Alternative F results in a greater loss of wetlands than any other alternative due to the frequent extended high flows, the far greater number of extended low flows, and the small number of seasons without extended high or low flows. The diversity of native community types under this alternative is expected to decrease 9% and is lower (statistically significant) than that under Alternative A and lower than any other alternative, primarily due to the large decreases in wetland community types.

Growing-season extended low flows resulting from low steady flows from July through October can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002) as wetlands dry and arrowweed colonizes former wetland areas. Wetlands transition to tamarisk with growing-season extended high flows in combination with extended low flows (Sher et al. 2000; Mortenson et al. 2012). The frequent extended high flows often shift all states to bare sand, which then shifts to tamarisk. Spring HFEs and growing-season extended high and low flows promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002; Mortenson et al. 2012). In addition, tamarisk communities are not expected to transition to other community types under this alternative, and as a result, this alternative would result in the greatest increase in tamarisk of any alternative (230.7 ac). Because of the large decrease in native community types (95.0 ac), the native to nonnative ratio under this alternative decreases 62% and is lower (statistically significant) than under Alternative A.

Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). Extended low flows combined with extended high flows result in the establishment of arrowweed on bare sand (Waring 1995). However, extended high flows followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Based on results of modeling, Alternative F would result in a 13% (22.2 ac) decrease in the arrowweed community type, with arrowweed cover being lower (statistically significant) than under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

In summary, Alternative F would result in a beneficial change associated with a decrease in arrowweed (13%, lower cover than under Alternative A). This benefit could be greater than anticipated, depending on the effects of vegetation treatments. However, Alternative F is also expected to result in adverse effects associated with a decrease in native cover (30% overall decrease in native plant community cover, 86% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (9%, lower diversity than under Alternative A), and decrease in the ratio of native to nonnative community types (62% decrease in ratio, a lower ratio than under Alternative A; 230.7 ac increase in tamarisk, greater cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover, and this decrease would be far greater than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. There is a small potential for impacts on active floodplain and Lake Mead shoreline special status species and benefit to inactive floodplain special status species. The Old High Water Zone would continue narrowing, although annual spring HFEs could result in higher survival rates of plants at lower elevations of the zone compared to Alternative A. Although the vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative F would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.6.3.7 Alternative G

This alternative includes sediment-triggered spring and fall HFEs, extended-duration fall HFEs (up to 336-hr, 45,000-cfs releases), and proactive spring HFEs in high volume years. Equal monthly volumes and steady flows conserve more sediment, and therefore result in more triggered HFEs. As a result, Alternative G has a far greater frequency of fall and spring HFEs compared to Alternative A and most other alternatives (Section 4.2). Because monthly volumes would be approximately equal, this alternative has a far greater number of extended low flows and fewer extended high flows compared to Alternative A.

Occasional extended high flows (although less frequent than under Alternative A) would result in a decrease in native community types through scouring and drowning, including wetlands, with there being more (statistically significant) of a decrease than under Alternative A. A greater frequency of HFEs and far more extended low flows would result in lack of establishment of native community types; consequently, native community types including wetlands decrease under this alternative (Ralston et al. 2008;Waring 1995; Anderson and Ruffner 1987), with the decrease being greater (statistically significant) than under Alternative A. Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002), and the establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This is supported by modeling results which indicate a 29% (93.7 ac) overall decrease in native plant community cover and 58% (2.6 ac) decrease in wetland community cover. The diversity of native community types under this alternative would be expected to decrease 3%, and would be lower than that under Alternative A, primarily due to the large decreases in the wetland community types.

Growing-season extended low flows along with an extended high flow can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). Growing-season extended low flows promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Spring HFEs in combination with growing-season extended low flows can also contribute to tamarisk establishment on bare sand (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012) or spring HFEs in combination with a growing-season extended high flow (Sher et al. 2000; Mortenson et al. 2012). Consequently, tamarisk-dominated communities would be expected to increase under Alternative G, a 46.4 ac increase based on results of modeling. Because of the large decrease in native community types (93.7 ac), the native to nonnative ratio under this alternative would decrease (40% decrease) a lower ratio (statistically significant) than under Alternative A.

Extended low flows can contribute to wetlands becoming replaced by arrowweed (Porter 2002), and extended low flows combined with extended high flows can result in the establishment of arrowweed on bare sand (Waring 1995). However, extended high flows followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002), and growing-season extended high flows contribute to the loss of arrowweed, resulting in bare sand (Kearsley and Ayers 1999; Ralston 2010). Based on the results of modeling, Alternative G would result in a 11% (20.1 ac) decrease in the arrowweed community type, with arrowweed cover being significantly lower (statistically significant) than for Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation camping goals.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

In summary, Alternative G would result in a beneficial change associated with a decrease in arrowweed (11%, lower cover than under Alternative A). This benefit could be greater than anticipated depending on the effects of the vegetation treatments. However, Alternative G is also expected to result in adverse effects associated with a decrease in native cover (29% overall decrease in native plant community cover, 58% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (3% decrease in native diversity over the LTEMP period, lower than under Alternative A), and reduction in the ratio of native to nonnative community types (40% decrease in ratio, a lower ratio than under Alternative A; 46.4 ac increase in tamarisk, greater cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover, and this reduction would be greater than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. There is a small potential for impacts on active floodplain special status species. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative G would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.7 WILDLIFE

This section addresses the effects of the LTEMP alternatives on wildlife, including special status species.

Issue: How do alternatives affect wildlife species in the project area?

Impact Indicators:

- Change in riparian and wetland wildlife habitats
- Change in aquatic habitats and food base used by wildlife
- Direct effects of HFEs and other flow and non-flow actions on wildlife

4.7.1 Analysis Methods

Models of the effects of alternatives on wildlife populations were not available for use in this analysis. This is, in part, a reflection of the relatively limited amount of quantitative data available on wildlife of Glen and Grand Canyons, which would serve as the basis of such models. Impact assessments are based on previous studies of wildlife in the project area and on the assessments conducted for aquatic ecology (Section 4.5) and vegetation (Section 4.6), because these assessments reflect impacts on terrestrial wildlife habitat and food production upon which wildlife species depend.

Impacts of LTEMP alternatives were evaluated for the following wildlife species groups (impacts on fish and other aquatic species are discussed in Section 4.5):

- Terrestrial invertebrates,
- Amphibians and reptiles,
- Birds,
- Mammals, and
- Special status species.

Impacts of each alternative on these species groups were evaluated based on the following impact indicators:

- Change in riparian and wetland wildlife habitats,
- Change in aquatic habitats and food base, and
- Direct effects of HFEs and other flow and non-flow actions on wildlife.

Other factors that could contribute to impacts on wildlife species and their habitats, such as climate change, defoliation of tamarisk by the tamarisk leaf beetle (*Diorhabda* spp.), noise, and uranium mining, are addressed as cumulative impacts (in Section 4.17.3.6).

4.7.2 Summary of Impacts

As described in Section 3.7, terrestrial wildlife populations in Glen and Grand Canyons are influenced by the availability of suitable habitat, food, and water resources. Of most importance for the analysis of the effects of LTEMP alternatives are those species dependent on riparian, wetland, and aquatic habitats, because these habitats could be directly and indirectly affected by LTEMP alternatives. Habitats above the riparian zone (mostly desert scrub) and the wildlife that inhabit those areas would be unaffected by LTEMP alternatives.

Water release patterns associated with both daily and monthly base operations, and experimental elements, particularly HFEs, are important factors that determine the coverage and characteristics of riparian vegetation and wetlands. Section 4.6 describes the anticipated changes in the characteristics of riparian vegetation communities over the LTEMP period; however, the anticipated impacts of the alternatives on vegetation relate to transitions among plant community types, not to increases or decreases in the amount of riparian and wetland vegetation coverage. None of the alternatives are expected to result in important structural changes in riparian habitat or overall riparian habitat coverage that could have population-level effects on terrestrial wildlife species. As noted in Section 4.5, there has been a net increase in vegetation since construction of the dam and none of the alternatives are expected to reverse these gains. In addition, many of the terrestrial wildlife species that occur in Glen and Grand canyons utilize a variety of terrestrial habitats and are not solely dependent on riparian habitat in general, or on the specific types of riparian vegetation that occur along the river. These factors reduce the potential for impacts of LTEMP alternatives on terrestrial wildlife.

Direct impacts of LTEMP alternatives on terrestrial wildlife species are possible, but these are likely to be short term. Although HFEs could displace less mobile species such as invertebrates, amphibians, and reptiles (Reclamation 2011b), these species can quickly recolonize disturbed areas from adjacent areas; most vertebrate animals that occupy riparian habitats are mobile enough to move in response to fluctuations in flow, and would return shortly after the HFE is over.

A summary of impacts of the LTEMP alternatives on various wildlife groups is presented in Table 4.7-1 and discussed below.

4.7.2.1 Terrestrial Invertebrates

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on terrestrial invertebrates. Invertebrates contribute to the diversity of the riparian corridor of the Colorado River and perform important ecological functions as decomposers, herbivores, predators, and pollinators. In addition, this diverse community of animals is an important component of the prey base of insectivorous vertebrates including fish, frogs, toads, lizards, snakes, songbirds, small mammals, and bats.

TABLE 4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts on wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; less nearshore habitat stability would result in decreased production of aquatic insects and would adversely impact species that eat insects or use nearshore areas, especially with the implementation of hydropower improvement flows; less decline of wetland habitat, however hydropower improvement flows would cause a greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat compared to Alternative A.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; least decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; increased production of aquatic insects due to more even monthly volumes could benefit species that eat insects or use nearshore areas, but benefits may be offset by higher within-day flow fluctuations.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greatest decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects (highest among alternatives) and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Terrestrial invertebrates	No change from current conditions.	Compared to Alternative A, potentially lower production of insects with aquatic and terrestrial life stages due to higher daily flow fluctuations. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential increase in production of insects with aquatic and terrestrial life stages due to more uniform monthly flows from December through August, lower daily range in flows. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential increase in production of insects with aquatic and terrestrial life stages due to more uniform monthly flows; experimental macroinvertebrate production flows may also increase insect production and diversity. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential slight increase in production due to more uniform monthly flows, but any increase could be offset by higher within-day flow fluctuations. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential increase in production of insects with aquatic and terrestrial life stages resulting from steady flows and relatively high spring flows. No effect on other terrestrial invertebrates.	Compared to Alternative A, year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest production of insects with aquatic and terrestrial life stages of all alternatives. No effect on other terrestrial invertebrates.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians and reptiles	Negligible impact on amphibians and reptiles; some decrease in wetland habitat from current condition, but no change in the stability of nearshore habitats that support adult and early life stages of amphibians and serve as food production areas for amphibians and reptiles. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, potentially lower insect production due to higher daily flow fluctuations. Second lowest wetland loss of any alternative. Hydropower improvement flows would have larger adverse effects on wetlands and food production than Alternative A. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, increase in habitat stability and insect production in nearshore habitats due to reduced daily fluctuations. Second highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, increase in habitat stability and insect production in nearshore habitats due to relatively even monthly release volumes; experimental macroinvertebrate production flows may increase insect production and diversity. Lowest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Negligible impact, similar to Alternative A.	Compared to Alternative A, increase in habitat stability and insect production in nearshore habitats due to steady flows. Highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives. Third highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect terrestrial birds over the long term. HFEs would occur outside of the breeding season of most birds.	Compared to Alternative A, larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on insect-eating birds and waterfowl using nearshore areas. HFEs would occur outside of the breeding season of most birds.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to reduced daily fluctuations. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to more even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season of some species (May), and could affect nesting birds in elevations below 45,000 cfs.	Similar to Alternative A.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to steady flows. Annual 45,000 cfs spike flow would be implemented during the nesting season of some species (May), and could affect nesting birds in elevations below 45,000 cfs.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to steady flows and even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season of some species (May), and could affect nesting birds in elevations below 45,000 cfs.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Mammals	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect mammals over the long term. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on semi-aquatic mammals and other mammals using nearshore areas. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to reduced daily fluctuations. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to reduced daily fluctuations. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to steady flows and even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

Most invertebrates in the riparian zone obtain their food from terrestrial sources, but the diets of some species (e.g., ground beetles, ants, and spiders) are also subsidized by emerging aquatic insects or by drifting aquatic organisms that become stranded in the varial zone (Paetzold et al. 2006). Some changes in the characteristics of vegetation communities (e.g., changes in diversity) and aquatic habitats may cause localized changes in terrestrial invertebrates (Anderson, B.W. 2012). Terrestrial invertebrates in the riparian zone recovered from the impacts of natural annual historic flood events, and are expected to recover quickly from HFEs (Reclamation 2011b). None of the LTEMP alternatives are expected to result in long-term population-level changes to terrestrial invertebrates.

Differences in the monthly and daily flow patterns of alternatives could affect the production of insects with aquatic and terrestrial life stages (e.g., blackflies, midges, and dragonflies) by affecting the stability of nearshore habitats and the amount of wetted area that supports these insects. Alternatives with more stable flows (Alternatives C, F, and G) and those with more even monthly release volumes (Alternatives C, D, E, and G) are expected to have higher production of these insects because of greater habitat stability; however, any differences among alternatives are expected to be relatively small (Section 4.5). The year-round steady flows of Alternative G are likely to result in the greatest production of these insects, and experimental macroinvertebrate production flows under Alternative D also target increased production and diversity. Although these experimental flows have not been tested, on a conceptual basis, providing steadier flows during important production months should produce more insects.

Experimental actions being considered under different alternatives also could adversely affect or benefit terrestrial invertebrates in the Colorado River corridor. For instance, experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to terrestrial invertebrates. Low summer flows under Alternatives C, D, E, and F could increase production of aquatic insects with terrestrial adult stages. TMFs under Alternatives B, C, D, E, and G are expected to have minor adverse effects on the production of aquatic insects with terrestrial life stages because very low flows that temporarily expose substrates would be very short lived (less than 1 day during a TMF cycle).

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would result in noticeable or measurable changes in invertebrates with only terrestrial life stages. However, alternatives with reduced fluctuations (Alternatives C, D, F, and G) or more even monthly release volumes (Alternatives C, D, E, and G) would have greater nearshore habitat stability, and could result in an increase in the production of insects with both aquatic and terrestrial life stages. Section 4.7.3 addresses the potential impacts on invertebrates under each LTEMP alternative.

4.7.2.2 Amphibians and Reptiles

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on amphibians and reptiles. Glen Canyon Dam operations may affect amphibians (including their aquatic larval stages) and reptiles along the Colorado River corridor, primarily though alterations of riparian and wetland habitats and effects on aquatic insect production (Dettman 2005). The effects of alternatives on amphibians (frogs and toads) could result from potential changes to wetland habitat and nearshore habitat that supports both adult and early life stages and serves as production areas for aquatic invertebrate prey. The effects of alternatives on reptiles (snakes and lizards) could result from potential changes in riparian vegetation and terrestrial invertebrate prey production. In addition, raised water levels from HFEs may drown some amphibians and reptiles that are unable to escape the rising water (Dettman 2005), or flood habitats used by amphibians and reptiles.

Amphibian and reptile populations along the river have increased under the modified Colorado River flow regime created by operation of Glen Canyon Dam (Section 3.7.2). Operations since completion of the dam have reduced the magnitude of spring floods and subsequently allowed an increase in riparian vegetation colonizing areas previously scoured by annual floods, and allowing the formation of wetlands under variable daily flows, but more consistent monthly flows (Reclamation 1995). Effects of alternatives on these habitats and the amphibians and reptiles supported by them are expected to be relatively small compared to these larger changes from pre-dam conditions.

Amphibians could be affected by the predicted decreases in wetland habitat area over the 20-year LTEMP period. Wetland area along the river corridor downstream of Glen Canyon Dam is limited (approximately 5 ac), making any loss potentially important for species dependent on wetland areas. Based on vegetation modeling presented in Section 4.6, wetland habitat is expected to decline over the LTEMP period under all alternatives, but impacts would be greater under alternatives with steadier flows (Alternatives C, F, and G) than alternatives with higher fluctuations (Alternatives A, B [except with experimental implementation of hydropower improvement flows], D, and E), which provide daily watering of habitats in the varial zone.

Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are expected to result in important structural changes in riparian habitat or vegetation productivity that could affect amphibians or reptiles over the long term. As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages are not expected to be affected differentially by alternatives, and those with both aquatic and terrestrial life stages are expected to benefit under certain alternatives (alternatives with lower within-day fluctuations, such as Alternatives C, F, and G, or more even monthly release volumes, such as Alternatives C, D, E, and G). Lower fluctuations would also result in potential benefits for the survival of amphibian eggs and tadpoles; however, as discussed in the previous paragraph, these alternatives also support less wetland habitat, which is important to amphibians. Lizards and snakes would benefit less from increases in aquatic-based food production because these reptiles are less dependent on these food sources than are amphibians.

In addition to these habitat and food-based impacts, HFEs can directly affect amphibians by disrupting breeding activities and by flushing egg masses and tadpoles from backwaters depending on the time of year in which they occur. Breeding and egg deposition occurs between April and July, with metamorphosis to adult occurring between June and August (Dettman 2005). Thus, any HFEs conducted between April and August (e.g., sediment-triggered spring

HFEs or proactive spring HFEs) are likely to result in some disruption of reproduction and/or mortality (Reclamation et al. 2002). Rising waters have the potential to trap lizards and snakes that are resident below the elevation of HFE flows and drown them or their buried eggs (Warren and Schwalbe 1985). In addition, possible reductions in riparian vegetation (e.g., from scouring) and direct mortality of prey items could lead to a decrease in prey availability (Dettman 2005; Reclamation et al. 2002). These effects are expected to be temporary and not to result in long-term effects on amphibian and reptile populations, because the area affected by scour would be small (below the elevation of 45,000 cfs flows) relative to total habitat availability, and recolonization of disturbed areas by vegetation and amphibian and reptile populations in adjacent unaffected areas is expected to occur. Prior to construction of the dam, flooding was an annual natural event in the Grand Canyon from which amphibians and reptiles recovered. Thus, they are expected to quickly recover from individual HFEs (Reclamation 2011b).

Other experiments being considered under different alternatives also could affect amphibians and reptiles in the Colorado River corridor. Experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to amphibians and reptiles. Activities associated with these treatments could disturb amphibians and reptiles in and adjacent to treatment areas, but this should be temporary unless individuals were inadvertently killed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates; this could in turn affect amphibians and reptiles that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on amphibians and reptiles because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). Mechanical removal of trout should have no effect on amphibians or reptiles.

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would affect amphibian and reptile populations. However, alternatives could produce changes in nearshore aquatic and wetland habitats occupied by some amphibian and reptile species, and those that serve as important food production areas for them (Table 4.7-1). Alternatives C, D, F, and G would produce more stable flows, which would favor food production in nearshore habitat areas, but these alternatives would provide less support for wetlands than would alternatives with higher fluctuations (Alternatives A, B, and E). Direct impacts from HFEs on amphibians and reptiles are expected to be negligible and temporary. Periodic flooding is a natural phenomenon along rivers; amphibian and reptile species have adapted to flooding and, from an ecosystem maintenance perspective, they are dependent on it. Section 4.7.3 addresses the potential impacts on amphibians and reptiles under each LTEMP alternative.

4.7.2.3 Birds

Riparian birds, many of which are protected under the Migratory Bird Treaty Act, have increased along the river corridor downstream of Glen Canyon Dam in response to an increase in riparian vegetation under dam operations (Brown et al. 1983; LaRue et al. 2001). In general, birds that use the Grand Canyon corridor temporarily during migration are not affected by Glen Canyon Dam operations; however, birds that breed or overwinter in the riparian zone can be directly and indirectly affected by operations. Table 4.7-1 summarizes the potential effects of LTEMP alternatives on birds.

Changes in riparian and wetland plant coverage can alter foraging and nesting habitats. Even the loss of less desirable vegetation such as tamarisk may have potential negative effects on bird species unless replaced promptly by native woody vegetation (Yard et al. 2004; see also Section 4.17.3.6). The structural complexity of riparian vegetation (e.g., tree, shrub, and ground vegetation layers) and the ecological function they provide is particularly important for many nesting birds (Sogge et al. 1998). Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period, but none of the alternatives are expected to result in significant structural changes in riparian habitat or vegetation productivity that could affect bird populations over the long term.

Differences in the monthly and daily flow patterns of alternatives could affect nearshore foraging areas used by waterfowl and wading birds. As discussed in Section 4.7.2.1, insects with only terrestrial life stages are not expected to be affected differentially by alternatives, and those with both aquatic and terrestrial life stages are expected to benefit under certain alternatives (those with lower within-day fluctuations or more even monthly release volumes such as Alternatives C, D, F, and G). These changes in food production could result in very minor adverse impacts on birds, in part because most birds forage over broad areas that include habitats outside of the river corridor.

In general, the potential for direct impacts of flows on birds would be greatest during the nesting period when nests could be inundated. Impacts of normal operating flows (between 5,000 and 20,000 cfs) are expected to be negligible because few birds nest in these areas (Sogge et al. 1998), and Brown and Johnson (1985) reported that flows up to 31,000 cfs do not affect the nests of riparian birds. Only flows above the normal operating range, such as HFEs, could affect nesting birds, and only if they occurred during the peak nesting period (May through August) because active nests could be destroyed by these high flows. For shrub-nesting songbirds such as Bell's vireo (*Vireo bellii*) and common yellowthroat (*Geothlypis trichas*), inundation of the ground below nests begins to occur at flows of about 36,000 cfs, and nest losses of 50% or more begin to occur from 40,000 to 62,000 cfs. These species can renest as long as high waters do not persist (Brown and Johnson 1985). The nests of some ground-nesting waterfowl species such as mallards (*Anas platyrhynchos*), gadwalls (*A. strepera*), and American wigeon (*A. americana*) could be more susceptible to HFEs than those of songbirds that nest in riparian vegetation, in part because these species breed earlier in the year when spring HFEs would be implemented. Sediment-triggered spring and fall HFEs would occur outside of the main nesting period for most birds, although proactive spring HFEs considered for testing under Alternatives C, D, and G could occur during the nesting period (April through June). Alternative F features an annual 45,000 cfs spike flow that would occur in May. HFEs outside of the nesting period are expected to only temporarily displace birds within the flood zone, and they are expected to use flooded areas once the high flows recede. Overall, riparian bird populations were unaffected by prior HFEs, so no effects are expected from proposed HFEs (Reclamation 2011b).

Waterfowl that winter in Glen and Grand Canyons would not be present during the months when spring and fall HFEs would most likely occur (March through June and October or November, respectively). Fall HFEs may have a short-term effect on foraging habitat and food resources for early-arriving winter waterfowl.

Other experiments being considered under different alternatives also could adversely affect or benefit birds in the Colorado River corridor. Experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to birds. Activities associated with these treatments could disturb birds in and adjacent to treatment areas, but this should be temporary unless nests were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, which could in turn affect birds that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on birds because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*) and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

In summary, none of the LTEMP alternatives are expected to produce changes in aquatic and riparian habitats that would result in long-term, population-level impacts on riparian bird populations. However, alternatives could produce changes in nearshore habitats that could affect waterfowl and wading birds; Alternatives C, D, F, and G would produce more stable nearshore habitat for these species. Direct impacts from HFEs on birds would be minimal, mostly because the timing of HFEs would occur outside of the peak breeding season. Under Alternatives C, D, and G, proactive spring HFEs would occur in high-volume release years (≥10 maf); these could occur during the peak nesting season (April through June) and result in the loss of some nests. Alternative F also could affect nesting birds, because it features an annual 45,000-cfs spike flow that would occur in May. Section 4.7.3 addresses the potential impacts on birds under each LTEMP alternative.

4.7.2.4 Mammals

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on mammals. Section 4.6 describes changes in the riparian vegetation community types over the LTEMP period, but these are not expected to result in important structural changes in riparian habitat or vegetation productivity that could affect mammal populations over the long term. Differences in the monthly and daily flow patterns of alternatives could have differential effects on the habitat stability of nearshore areas used by semi-aquatic mammals and other mammals using nearshore areas. As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages are not expected to be affected differentially by alternatives and those with both aquatic and terrestrial life stages are expected to benefit from alternatives with more stable flows. These changes in food production are expected to result in very minor effects on insect-eating mammals, such as shrews, mice, and bats. Riparian vegetation changes during the LTEMP period are not expected to have adverse impacts on habitat or food resources for herbivorous mammals that occupy riparian habitats.

HFEs may have direct impacts on some mammals. Less mobile species such as shrews, mice, and other small mammals may drown, but some individuals would be able to move upslope away from floodwaters. Recolonization of flooded areas would be expected to occur rapidly. Ground nests also could be destroyed. Many small mammals produce multiple litters each year, which may compensate for small mammal losses from an individual HFE (Dettman 2005). No long-term population-level impacts on these mammals are anticipated.

Along the Colorado River, American beavers (*Castor canadensis*) inhabit and raise their young in bank dens, which they create near the water's edge; the lack of high flows allows them to build their dens lower down in the banks. HFEs may drown young or adults in their bank dens (Dettman 2005; Reclamation et al. 2002). HFEs affect muskrats (*Ondatra zibethicus*) similarly (Reclamation 2011b). Young born prior to a spring or proactive spring HFE may drown if they are located below the flood stage and are unable to leave the lodge. Fall HFEs are unlikely to impact the American beaver or muskrat because they would be able to leave their dens and swim to safety (Reclamation 2011b). These species regularly occur in riverine habitats subjected to regular flood flows, and are adapted to these conditions both in terms of their ability to respond to increases in flow and to recolonize areas affected by HFEs.

Large carnivores such as the cougar (*Puma concolor*) would experience minimal impacts from dam operations because they generally have large ranges and can obtain prey from both riparian and upland (desert) communities. Similarly, bighorn sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) are highly mobile and use a variety of habitats within the Grand Canyon, including non-riparian habitats (Dettman 2005).

Other experiments being considered under different alternatives also could adversely affect or benefit mammals in the Colorado River corridor. Experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to mammals. Activities associated with these treatments could disturb mammals in and adjacent to treatment areas, but this should be temporary unless individuals, nests, or roosts were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, and this could in turn affect mammals that consume terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on mammals because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). Mechanical removal of trout should have no effect on mammals.

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would affect mammal populations. Direct impacts from HFEs on mammals would be negligible and temporary, and no long-term population-level impacts are expected. Section 4.7.3 addresses the potential impacts on mammals under each LTEMP alternative.

4.7.2.5 Special Status Species

Eleven special status wildlife species, listed under the Endangered Species Act, Bald and Golden Eagle Protection Act, or the State of Arizona, are known to occur or could occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead (Section 3.7). Potential impacts on these species from LTEMP alternatives are summarized in Table 4.7-2 and discussed below. A Biological Assessment (BA; see Appendix O) has been prepared for three of these species that are currently listed under the Endangered Species Act (ESA) and that may be impacted by LTEMP operations: Kanab ambersnail (*Oxyloma haydeni kanabensis*), Ridgway's rail (Yuma) (*Rallus obsoletus yumanensis*), and southwestern willow flycatcher (*Empidonax traillii extimus*).

The effects of dam operations and HFEs under the LTEMP alternatives are discussed for each special status species below. Other experiments being considered under different alternatives also could adversely affect or benefit these species in the Colorado River corridor. Experimental vegetation treatments (common to all alternatives except Alternative A) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to special status species. Activities associated with these treatments could disturb special status birds and bats in and adjacent to treatment areas, but this should be temporary unless nests or roosts were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, and this could in turn affect special status species that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on special status species because the flows would last for a 3-month period during the growing season while the low flows of TMFs would be of short duration (less than 1 day). TMFs and trout removal in the Little Colorado River reach could have a minor effect on osprey (*Pandion haliaetus*) and bald eagle (*Haliaeetus leucocephalus*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species.

Section 4.7.3 addresses the potential impacts on the special status species under each LTEMP alternative, including potential impacts of condition-dependent and experimental elements of the alternatives. For species listed under the ESA, Appendix O presents the BA prepared for Section 7 consultation with the U.S. Fish and Wildlife Service (FWS).

TABLE 4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife Species

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Losses of habitat and individuals of Kanab ambersnail. Decrease in potential wetland habitat for northern leopard frog and Ridgway's rail (Yuma). Sediment-triggered spring HFEs could adversely affect nests of Ridgway's rail (Yuma). No impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar; similar decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma), but greater potential decrease under hydropower improvement flows; sediment-triggered spring HFEs could adversely affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population; greater decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma) compared to Alternative A; proactive spring HFEs could occur during the nesting period of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population; least wetland loss of any alternative would minimize habitat loss for northern leopard frog and Ridgway's rail (Yuma); proactive spring HFEs could occur during the nesting period of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Ridgway's rail (Yuma). No impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency could inhibit rebound of the population; similar decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma); spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration annual high flow in May could inhibit rebound of the population; greater decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma); annual extended-duration high flow in May could occur during the nesting period of southwestern willow flycatcher; spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population; greater decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma); proactive spring HFEs could occur during the nesting period of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Invertebrates							
Kanab ambersnail (*Oxyloma haydeni kanabensis*) ESA-E; AZ-SGCN	No change from current conditions. The average of 5.5 HFEs and maximum of 14 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise through the early portion of the LTEMP period (HFEs would expire in 2020); some rebound between HFEs and after 2020 would be expected; no impacts would occur on the Elves Chasm population.	The average of 7.2 HFEs and maximum of 10 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the low frequency of HFEs would allow some rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 21.3 HFEs and maximum 40 HFEs could cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 21.1 HFEs and maximum 38 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 17.1 HFEs and maximum 30 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 38.1 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and the annual extended-duration high flow in May would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 24.5 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians							
Northern leopard frog (*Lithobates pipiens*) AZ-SGCN	Species may already be extirpated downstream of Glen Canyon Dam. Negligible change from current condition. Some decrease in wetland habitat, but no change in the stability of nearshore habitats that support adult and early life stages and serve as food production areas.	Compaed to Alternative A, potentially lower insect production due to higher daily flow fluctuations; hydropower improvement flows would have larger adverse effects on wetlands and food production.	Compared to Alternative A, potential benefit due to an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations, but these benefits could be offset by greater wetland losses.	Compared to Alternative A, potential benefit due to lowest wetland habitat loss and an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations and relatively even monthly release volumes; experimental macroinvertebrate production flows may also increase insect production and diversity.	Compared to Alternative A, potentially lower insect production due to higher daily flow fluctuations; greater wetland loss.	Compared to Alternative A, potential benefit due to an increase in habitat stability and insect production in nearshore habitats due to steady flows, but these benefits could be offset by greater wetland losses.	Compared to Alternative A, year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives; these benefits could be offset by greater wetland losses
Birds							
American peregrine falcon (*Falco peregrinus*) AZ-SGCN	No change from current conditions related to food or habitat availability for the American peregrine falcon.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Bald eagle (*Haliaeetus leucocephalus*) BGEPA; AZ-SGCN	No change from current conditions related to food or habitat availability for the bald eagle.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
California condor (*Gymnogyps californianus*) ESA-EXPN; AZ-SGCN	No change from current conditions related to food or habitat availability for the California condor.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Golden eagle (*Aquila chrysaetos*) BGEPA; AZ-SGCN	No change from current conditions related to food or habitat availability for the golden eagle.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Osprey (*Pandion haliaetus*) AZ-SGCN	No change from current conditions related to food or habitat availability for the osprey.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Ridgway's rail (Yuma) (*Rallus obsoletus yumanensis*) ESA-E; AZ-SGCN	No change from current conditions. Unlikely that nests or suitable habitat would be close enough to the river to be impacted by sediment-triggered spring HFEs that coincide with the nesting period (April and May). Fall HFEs would not occur during the nesting season.	Same as Alternative A.	Compared to Alternative A, greater wetland loss.	Same as Alternative A.	Compared to Alternative A, greater wetland loss.	Compared to Alternative A, greatest wetland loss could adversely affect this species.	Compared to Alternative A, greater wetland loss.
Southwestern willow flycatcher (*Empidonax traillii extimus*) ESA-E; AZ-SGCN	No change from current conditions. Sediment-triggered HFEs would not occur during the nesting period.	Same as Alternative A.	Proactive spring HFEs could occur during the nesting period, but nests in the Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period.	Proactive spring HFEs could occur during the nesting period, but nests in the Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period.	Same as Alternative A.	Annual 45,000-cfs high flow could occur during the nesting period, but nests in the Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period. Annual low summer flows could affect the species by drying riparian habitat.	Proactive spring HFEs could occur during the nesting period, but nests inthe Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) ESA-T(DPS); AZ-SGCN	No impact on the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Mammals							
Spotted bat (*Euderma maculatum*) AZ-SGCN	No impact on current conditions related to food or habitat availability for the spotted bat.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

[a] AZ-SGCN = Arizona Wildlife Species of Greatest Conservation Need; BGEPA = Protected under the Bald and Golden Eagle Protection Act; ESA-E = Endangered Species Act-Endangered; ESA-EXPN = Endangered Species Act-Experimental Population, Non-Essential; ESA-T(DPS) = Endangered Species Act-Threatened (Distinct Population Segment).

Kanab Ambersnail (*Oxyloma haydeni kanabensis*)

Within the Grand Canyon, populations of the Kanab ambersnail occur at Vasey's Paradise and Elves Chasm. Because the Elves Chasm population is located above the 100,000 cfs stage (FWS 2008), this population would not be affected by any of the LTEMP alternatives. At Vasey's Paradise, very little Kanab ambersnail habitat and only a few individuals occur below the 25,000-cfs stage (Meretsky and Wegner 2000; Sorensen 2009). Most Kanab ambersnail habitat is located above the 33,000 cfs stage (Reclamation 2011b). HFEs may scour or inundate portions of Kanab ambersnail habitat (Kennedy and Ralston 2011). The November 1997 test flow of 31,000 cfs scoured 1% (7 m^2) of Kanab ambersnail habitat (FWS 2008). HFEs of 45,000 cfs cause a temporary loss of as much as 17% (119 m^2) of Kanab ambersnail habitat (FWS 2008). Surveys conducted after HFEs revealed no population-level declines in the Kanab ambersnail population (Kennedy and Ralston 2011). Kanab ambersnails can survive up to 32 hours underwater in cold, well-oxygenated water (FWS 2011c); so as long as they are not washed away, they could survive inundation from the short-term HFEs. The effects of extended-duration HFEs (up to 250 hr in length) proposed under Alternatives C, D, and G, and the extended-duration high flow in May under Alternative F are not known, but they could pose a greater threat to Kanab ambersnail habitat within the area affected by 45,000-cfs flows.

Recovery of ambersnail habitat scoured by HFEs can take 2.5 years (Sorensen 2009). Therefore, frequent HFEs or extended-duration HFEs may result in long-term loss of ambersnail habitat that occurs below the 45,000-cfs flow level (FWS 2011c). However, the snails survived and persisted through natural pre-dam floods and the 1983 high flows (Reclamation 1995), which were much larger in magnitude and duration than HFEs proposed under the LTEMP, so HFEs may not represent a substantial threat to the persistence of the Kanab ambersnail (Kennedy and Ralston 2011).

Northern Leopard Frog (*Lithobates pipiens*)

Only one population of northern leopard frogs, located within the Glen Canyon National Recreation Area (GCNRA), has been recorded along the Colorado River between Glen Canyon Dam and Lake Mead. However, individuals have not been observed at this location since 2004 (Drost 2005), and it is possible this population has been extirpated.[19] If the species still occurs in Glen Canyon, operations and experiments under the LTEMP alternatives could affect it by affecting the extent of wetland habitat, production of terrestrial invertebrates, or the stability of nearshore habitats potentially used by adults and early life stages. As discussed in Section 4.6.2.2, alternatives could produce changes in nearshore aquatic and wetland habitats. Alternatives C, D, F, and G would produce more stable flows, which would favor food production in nearshore areas and provide higher quality habitats for adults and early life stages of the leopard frog, but Alternatives C, E, F, and G would provide less support for wetlands than

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[19] In 2013, GCNRA, Grand Canyon Wildlands Council, FWS, and AZGFD began collaborating to restore northern leopard frog habitat at Leopard Frog Marsh (RM -9.0). In 2016, a northern leopard frog reintroduction plan was developed and may be implemented in the next 1–2 years.

would alternatives with higher fluctuations (Alternatives A and B) or Alternative D, which would result in the least wetland loss of any alternatives.

American Peregrine Falcon (*Falco peregrinus*)

Any impacts on the American peregrine falcon from dam operations are likely to be indirect, possibly through influences on the distribution and abundance of aquatic and terrestrial macroinvertebrate populations, which in turn would influence the availability of prey such as swifts, other songbirds, bats, and—in winter—waterfowl (Holmes et al. 2005). However, based on the evaluations presented in Sections 4.7.2.1 (invertebrates) and 4.7.2.3 (birds), differences among alternatives are expected to be small and not affect the abundance of food available to peregrine falcons. No effects of alternatives on foraging habitats (riverine, riparian, and desert areas) or roosting and nesting habitats (cliffs) are anticipated.

Bald Eagle (*Haliaeetus leucocephalus*)

Bald eagles migrate through and overwinter in Marble Canyon and the upper half of the Grand Canyon. There is no evidence that bald eagle abundance is directly affected by river flows (Holmes et al. 2005). During low river flows, bald eagles can capture and scavenge proportionally more prey from isolated pools and nearshore habitats. Inundation of these habitats during high flows reduces or eliminates prey availability (Brown et al. 1989). During the winters of 1990 and 1991, bald eagle foraging in the river, nearshore, and isolated pool habitats of the Colorado River decreased to 0% at flows >20,000 cfs; foraging in adjacent creek habitat increased to 100% (Brown et al. 1998). These observations demonstrate the ability of eagles to respond to changes in foraging conditions by moving to more favorable areas nearby. Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have negligible effects on the ability of eagles to find and catch fish. TMFs and trout removal in the Little Colorado River reach could have a minor effect on the bald eagle, because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species. Alternatives would have no effect on habitats used for roosting (cliffs or trees). Wintering and migrant bald eagles are generally not present during the months in which spring and fall HFEs would occur (Sogge et al. 1995).

California Condor (*Gymnogyps californianus*)

California condors are opportunistic scavengers that consume carcasses of mammals, birds, and fishes. Along the Colorado River corridor in Glen and Grand Canyons, they utilize cliff locations for roosting, and beaches when drinking, resting, preening, and feeding (Section 3.7). No impacts on the California condor are anticipated from LTEMP activities.

Golden Eagle (*Aquila chrysaetos*)

Golden eagles are rare to uncommon residents and rare fall migrants throughout the region (Gatlin 2013). None of the alternatives are expected to impact golden eagles, because they nest on cliff edges and primarily feed on upland terrestrial wildlife. Indirect effects of LTEMP alternatives on the abundance of mammals and other prey items within the narrow riparian zone would be negligible, because the home range of the golden eagle can be over 300 km^2 (NatureServe 2014). No impacts on the golden eagle are anticipated from LTEMP activities.

Osprey (*Pandion haliaetus*)

Ospreys typically occur along the Colorado River during their fall migration (August–September), although a nesting pair successfully fledged young in 2014, 2015, and 2016 near the dam (Section 3.7). Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have negligible effects on the ability of osprey to find and catch fish. TMFs and trout removal in the Little Colorado River reach could have a minor effect on osprey (*Pandion haliaetus*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species. There would be no effect of alternatives on habitats used for roosting (cliffs or trees) or nesting. Section 4.7.3 addresses the potential impacts on the osprey under each LTEMP alternative.

Ridgway's Rail (Yuma) (*Rallus obsoletus yumanensis*)

The Ridgway's rail (Yuma) inhabits marshes dominated by emergent plants. Generally, it is associated with dense riparian and marsh vegetation dominated by cattails and bulrushes along margins of shallow ponds with stable water levels (FWS 2014c). It is only a casual visitor to marshy mainstem riparian habitats along the Colorado River downstream of Separation Canyon (e.g., RM 227 and 246 and near Burnt Springs). The only confirmed nesting was reported in 1996. Its occurrence along the Colorado River in the affected area only was documented once suitable habitat was created through dam construction (FWS 2014c). Other than predation, the main threats to the rail include habitat destruction, primarily due to stream channelization and drying and flooding of marshes resulting from water flow management (FWS 2014c). Sediment-triggered spring or proactive spring HFEs under Alternatives C, D, and G, and annual 45,000-cfs releases under Alternative F could cause inundation of rail nests or habitat, although it is unlikely that nests or habitat would be close enough to the river to be affected. All alternatives would have spring HFEs, but these are expected to be less frequent for Alternatives A, B, and E. Fall HFEs would not coincide with the nesting period of the Ridgway's rail (Yuma). Low summer flow experiments under Alternatives C, D, and E are not expected to have long-term effects on potential Ridgway's rail (Yuma) habitat. Wetland habitat loss under Alternatives C, E, F, and G could affect this species.

Southwestern Willow Flycatcher (*Empidonax traillii extimus*)

The southwestern willow flycatcher nests and forages in habitats ranging from dense, multi-storied riparian vegetation (such as cottonwood/willow stands with a mix of trees and shrubs) to dense tamarisk stands with little layering of vegetation. However, changes in the availability of suitable habitat may not necessarily translate into changes in the southwestern willow flycatcher populations. Despite the abundance of woody riparian vegetation (e.g., tamarisk) since construction of the Glen Canyon Dam, numbers of nesting southwestern willow flycatchers in the Grand Canyon have declined since the 1980s and no nests have been confirmed in the Grand Canyon since 2007. Nest surveys conducted between Lees Ferry and Phantom Ranch and between Diamond Creek and Pearce Ferry in 2008 detected no nests. No other nest surveys were conducted between 2008 and 2012 (Stroud-Settles et al. 2013).

The effect of HFEs on the southwestern willow flycatcher depends on whether the HFE enhances or substantially reduces riparian habitat at potential breeding sites (Holmes et al. 2005). All alternatives include sediment-triggered spring HFEs; Alternatives C, D, and G include proactive spring HFEs in May or June that coincide with the nesting period of the southwestern willow flycatcher. Alternative F features an annual 45,000-cfs spike flow that also coincides with the nesting period. However, southwestern willow flycatchers nests in the Grand Canyon have typically been located above the elevation of 45,000-cfs flows (Gloss et al. 2005), and thus may not be affected by the HFEs that would be implemented under the LTEMP alternatives. Most spring HFEs would occur prior to nest initiation for the southwestern willow flycatcher and would have no direct impact on the species. Fall HFEs occur long after nesting and fledging dates of the southwestern willow flycatcher (see Appendix O).

In addition to HFEs, lower flows during the May to August nesting period can have a negative effect on southwestern willow flycatchers by drying riparian habitat (Reclamation 2007d). Normal operations under most alternatives would have monthly average flows of 10,000 cfs or more during the nesting period, except for Alternative F, with low steady flows in summer through winter (July through February), and during the experimental implementation of low summer flows under Alternatives C, D, and E. Under these three alternatives, there is the potential for some dewatering of nesting habitat. Only under Alternative F could these impacts be long term, because low summer flows would occur annually under this alternative; low summer flow experiments under Alternatives C and D would occur relatively infrequently and are not expected to have long-term effects on nesting habitat.

Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are expected to result in important structural changes in riparian habitat or vegetation productivity that could affect the southwestern willow flycatcher.

As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages, are not expected to be affected differentially by alternatives, and those invertebrates with both aquatic and terrestrial life stages are expected to benefit from alternatives with more stable flows. These changes in food production are expected to result in negligible impacts on the southwestern willow flycatcher.

In summary, only Alternative F is expected to produce changes in riparian habitats (through regular low summer flows) that would affect the southwestern willow flycatcher. Direct impacts from HFEs on nesting flycatchers are not anticipated, mostly because the timing of HFEs would be outside of the peak breeding season, but also because nests are typically at elevations above that of a 45,000-cfs flow. Alternatives C, D, F, and G could have high flows that occur during the peak nesting season; proactive spring HFEs under these three alternatives would occur in high volume release years (≥10 maf). Alternative F features an annual 45,000-cfs spike flow that would occur in May.

Western Yellow-Billed Cuckoo (*Coccyzus americanus occidentalis*)

The western yellow-billed cuckoo occurs at a number of sites in the lower Grand Canyon, near the Lake Mead delta where mature cottonwood forests are located. It requires structurally complex riparian habitats with tall trees and a multi-storied vegetative understory; the large caterpillars on which it feeds depend on cottonwoods and willows (Section 3.7). It is a rare restricted transient in dense tamarisk thickets, with a few observations in the Lees Ferry reach (Spence et al. 2011). Cottonwood/willow habitats that support the western yellow-billed cuckoo are not expected to be affected by any of the LTEMP alternatives.

Spotted Bat (*Euderma maculatum*)

Most spotted bats occur in dry, rough desert shrublands or in pine forest communities. These habitats are all located well above the river corridor and the area potentially affected by Glen Canyon Dam operations. Their roost sites, including hibernacula, do not occur within the area along the Colorado River affected by daily operations and HFEs. Only negligible adverse effects on insects, the prey base for the spotted bat, would occur under any of the alternatives, and the spotted bat can feed within upland areas that would not be impacted by LTEMP operations. The spotted bat is not expected to be affected by any of the LTEMP alternatives.

4.7.3 Alternative-Specific Impacts on Wildlife

This section describes alternative-specific impacts on wildlife, including special status wildlife species. More detailed descriptions of the basis of impacts and supporting literature citations for these impacts are presented in Section 4.6.2. Tables 4.7-1 and 4.7-2 summarize the potential impacts of all alternatives on wildlife and special status wildlife species, respectively.

4.7.3.1 Alternative A (No Action Alternative)

Changes in riparian habitats under Alternative A would not result in noticeable or measurable changes in invertebrates with only terrestrial life stages (Table 4.7-1). Because aquatic food base productivity under Alternative A would be similar to current conditions

(Table 4.5-1), the contribution of aquatic insects with a terrestrial adult stage to the prey base for wildlife that consume invertebrates will also remain unchanged.

Changes in riparian habitats under Alternative A would not affect amphibian, reptile, bird, or mammal populations, but some amphibians and other wetland-dependent species could be affected by wetland habitat decline expected under Alternative A (Section 4.7.2). The higher flow fluctuations under Alternative A, which provide daily watering of habitats in the varial zone, would limit wetland habitat loss. The effects of HFEs on reptiles and amphibians are expected to be temporary and not result in long-term population effects because the area affected would be small (below the elevation of 45,000-cfs flows) relative to total habitat availability, and recolonization of disturbed areas by vegetation and by amphibians and reptiles following HFEs are expected to occur rapidly from nearby unaffected areas.

No important structural changes in riparian habitat or vegetation productivity are expected under Alternative A that could affect bird populations over the long term. HFEs under Alternative A would occur outside the main nesting period of birds and are expected to only temporarily displace birds within the flood zone. Fall HFEs may have a short-term effect on foraging habitat and food resources for early-arriving winter waterfowl. Potential effects of HFEs, although negligible, would not occur after 2020 under Alternative A.

No important structural changes in riparian habitat or vegetation productivity are expected under Alternative A that could affect mammal populations over the long term. HFEs could cause the direct loss of individuals belonging to less mobile species (e.g., small mammals). Recolonization of flooded areas would be expected to occur rapidly. High reproductive rates of most small mammals may compensate losses. HFEs, which would only occur through 2020, may also cause the loss of some individual American beavers and muskrats, but long-term population-level effects are not anticipated (Section 4.7.2.4). Minimal impacts are expected for bats and large mammals.

Impacts of Alternative A on special status wildlife species are summarized in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, southwestern willow flycatcher, spotted bat, and western yellow-billed cuckoo. HFEs could cause losses of habitat and individuals in <20% of occupied habitat of the Vasey's Paradise population of the Kanab ambersnail. Some rebound from the losses would occur between HFEs or after 2020, when HFEs would expire. No impacts are expected on the Elves Chasm population. A 28% decrease in wetland habitat may cause a change in potential habitat of the northern leopard frog (which may already be extirpated downstream of Glen Canyon Dam) and Ridgway's rail (Yuma) (which has not been observed nesting in the area since 1996).

In summary, under Alternative A, there would be little or no change from current conditions for most wildlife species, including special status species, with the exception of a potential impact on amphibians and other species dependent on wetland habitats, including the northern leopard frog and Ridgway's rail (Yuma). HFEs could cause losses of habitat and individuals in <20% of occupied habitat of the Vasey's Paradise population of the Kanab ambersnail. Some rebound from the losses would occur between HFEs or after 2020, when HFEs would expire. There would be no impacts on other special status wildlife species.

4.7.3.2 Alternative B

Impacts of Alternative B on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1), but there would be less impact on wetland habitat (i.e., 20% decrease compared to 28% for Alternative A), except with the implementation of experimental hydropower improvement flows, which could cause an 83% decrease in wetland habitat. There would be slightly more HFEs under Alternative B (mean of 7.2 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by HFEs, but these impacts are not expected to result in long-term population-level effects. Higher daily flow fluctuations would reduce nearshore habitat stability, especially with experimental hydropower improvement flows, and could lower production of insects with aquatic and terrestrial life stages, and impact amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or utilize nearshore areas. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative B on special status wildlife species are presented in Table 4.7-2. As under Alternative A, no impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, southwestern willow flycatcher, spotted bat, and western yellow-billed cuckoo. Impacts on the Kanab ambersnail would be similar to those under Alternative A, although riparian vegetation treatments could occur on rare occasions near or within habitat at Vasey's Paradise, which could disturb some individuals and habitats. Larger negative wetland and food production losses from hydropower improvement flows under Alternative B may have greater effects on the northern leopard frog (which may be already be extirpated downstream of Glen Canyon Dam) and the Ridgway's rail (Yuma) (which has not been observed nesting in the area since 1996).

In summary, impacts of Alternative B on most terrestrial wildlife species would be similar to those under Alternative A. Higher fluctuations under Alternative B would reduce nearshore habitat stability and result in lower production of aquatic insects, which could impact species that eat insects or use nearshore areas. Experimental implementation of hydropower improvement flows would result in adverse impacts on wetland habitat. There would be some losses of habitat and individuals of Kanab ambersnail associated with HFEs comparable to those under Alternative A, but riparian vegetation treatments could affect individuals and habitat. There would be no impacts on other special status wildlife species.

4.7.3.3 Alternative C

Impacts of Alternative C on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (75% decrease compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative C (mean of 21.3 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5), which could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs; however, these impacts are not expected to result in long-term population-level effects. More uniform monthly flows from December through August under Alternative C compared to Alternative A may increase the production of insects with aquatic and terrestrial life stages. In addition, an increase in habitat stability of nearshore habitats compared to Alternative A may result from lower within-day fluctuations. Both increases in insect production and nearshore habitat stability may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore areas. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative C on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. More frequent HFEs and extended-duration HFEs could adversely affect Kanab ambersnail and Ridgway’s rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey’s Paradise, which could disturb some individuals and habitats. Greater wetland habitat loss compared to Alternative A could adversely affect northern leopard frog and Ridgway’s rail (Yuma). Proactive spring HFEs could occur in May and June, affecting nesting habitat of the southwestern willow flycatcher, although the species generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered spring HFEs would occur outside the nesting period of the southwestern willow flycatcher. Experimental low summer flows under Alternative C could result in drying of some nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on this habitat.

In summary, impacts of Alternative C on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly release volumes and lower fluctuations under Alternative C would provide more stable nearshore habitats and result in higher production of aquatic insects compared to Alternative A, potentially benefitting wildlife that eat insects and use nearshore areas. Compared to Alternative A, Alternative C is expected to result in minor impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway’s rail (Yuma) (wetland loss and HFE effects on nests), and southwestern willow flycatcher (proactive spring HFE effects on nesting habitat). There would be no impacts on other special status wildlife species.

4.7.3.4 Alternative D (Preferred Alternative)[20]

Impacts of Alternative D on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a smaller loss of wetland habitat (16% decrease compared to a 28% decrease), which could benefit wetland-dependent amphibians, reptiles, and birds; Alternative D has the lowest expected wetland loss among all alternatives. There would be more HFEs (mean of 21.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5), which could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term, population-level effects. More uniform monthly flows throughout the year under Alternative D compared to Alternative A would provide more stable aquatic habitats and may increase the production of insects with aquatic and terrestrial life stages. Experimental macroinvertebrate production flows may also increase production and diversity of aquatic insects with terrestrial life stages. More stable nearshore habitat and insect production may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore habitats. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron, and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative D on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. More frequent HFEs and extended-duration HFEs compared to those under Alternative A could affect Kanab ambersnail and Ridgway's rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. There would be less wetland habitat loss under this alternative, thus reducing impacts on northern leopard frog and Ridgway's rail (Yuma). Proactive spring HFEs could occur in May and June, affecting nesting habitat of the southwestern willow flycatcher, although the species generally nests above the area that are inundated by 45,000-cfs flows. Sediment-triggered HFEs would occur outside the nesting period for the species. Experimental low summer flows could result in drying of some of nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on southwestern willow flycatcher nesting habitat.

In summary, impacts of Alternative D on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly release volumes under Alternative D would provide greater nearshore habitat stability and result in higher production of aquatic insects compared to Alternative A, potentially benefiting species that eat insects or use nearshore areas. Experimental macroinvertebrate production flows could also increase insect production. Compared to Alternative A, Alternative D is expected to result in a lower impact on northern

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[20] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on wildlife.

leopard frog (less wetland loss), and Ridgway's rail (Yuma) (less wetland loss), but greater impact on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), Ridgway's rail (Yuma) (HFE effects on nests), and southwestern willow flycatcher (proactive spring HFE effects on nesting habitats). There would be no impacts on other special status wildlife species.

4.7.3.5 Alternative E

Impacts of Alternative E on most terrestrial wildlife would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a slightly greater loss of wetland habitat under Alternative E (38% compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative E (mean of 17.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term population-level effects. More uniform monthly flows may increase production of aquatic insects compared to Alternative A, but this may be offset by higher within-day flow fluctuations, which would reduce habitat stability. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative E on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, southwestern willow flycatcher, spotted bat, and western yellow-billed cuckoo. Impacts on the Kanab ambersnail would be similar to those under Alternative A; however, more frequent HFEs may prevent recolonization of impacted habitat over the long term. Greater wetland habitat loss under Alternative E could affect the northern leopard frog and Ridway's rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. Sediment-triggered HFEs would occur outside the nesting period for the southwestern willow flycatcher. Experimental low summer flows could result in drying of some nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on southwestern willow flycatcher nesting habitat.

In summary, impacts of Alternative E on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly flows under Alternative E would provide greater nearshore habitat stability and result in higher production of aquatic insects, and potential benefits for species that eat insects, but these benefits may be offset by higher within-day fluctuations. Compared to Alternative A, Alternative E is expected to result in minor impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway's rail (Yuma), and southwestern willow flycatcher (wetland loss and HFE effects on habitat). There would be no impacts on other special status wildlife species.

4.7.3.6 Alternative F

Impacts of Alternative F on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (86% decrease compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. Wetland habitat loss would be higher for Alternative F than for all other alternatives. There would be more HFEs under Alternative F (mean of 38.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term population-level effects; their frequency under this alternative would be comparable to the frequency of annual floods in the pre-dam river. Steady flows and relatively high spring flows under Alternative F compared to Alternative A may increase the production of insects with aquatic and terrestrial life stages. This, in addition to an increase in habitat stability of nearshore habitats compared to Alternative A, may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore areas.

Impacts of Alternative F on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. Impacts on the Kanab ambersnail would be similar to those under Alternative A; however, more frequent HFEs may prevent recolonization of impacted habitat over the long term. Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey’s Paradise, which could disturb some individuals and habitats. The relatively large decrease in wetland habitat compared to other alternatives may affect the northern leopard frog and Ridgway’s rail (Yuma). The annual 1-day 45,000-cfs flow in May could affect nesting habitat of the southwestern willow flycatcher, although it generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered HFEs would not occur during the nesting period of the southwestern willow flycatcher. Annual low summer flows under Alternative F could result in drying of some nesting habitat, and could have long-term effects on southwestern willow flycatcher nesting habitat.

In summary, impacts of Alternative F on most terrestrial wildlife species would be similar to those under Alternative A. Steady flows under Alternative F would provide greater nearshore habitat stability and result in higher production of aquatic insects compared to Alternative A, and would benefit species that eat insects or use nearshore areas. Compared to Alternative A, Alternative F is expected to result in minor impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway’s rail (Yuma) (wetland loss and HFE effects on nests), and southwestern willow flycatcher (high spring flow and low summer flow effects on nesting habitats). There would be no impacts on other special status wildlife species.

4.7.3.7 Alternative G

Impacts of Alternative G on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (58% decrease compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative G (mean of 24.5 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term, population-level effects. Year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest production of insects with aquatic and terrestrial life stages. These conditions may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore habitats. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative G on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. More frequent HFEs and extended-duration HFEs could affect Kanab ambersnail and Ridgway's rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. Greater wetland habitat loss compared to Alternative A could affect northern leopard frog and Ridgway's rail (Yuma). Proactive spring HFEs could occur in May and June, affecting nesting habitat of the southwestern willow flycatcher, although it generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered spring and fall HFEs would not occur during the nesting period of the southwestern willow flycatcher.

In summary, impacts of Alternative G on most terrestrial wildlife species would be similar to those under Alternative A. Steady flows under Alternative G would provide greater nearshore habitat stability, result in higher production of aquatic insects, and benefit species that eat insects or use nearshore areas. Compared to Alternative A, Alternative G is expected to result in minor adverse impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway's rail (Yuma) (wetland loss and HFE effects on nests), and southwestern willow flycatcher (proactive spring HFE effects on nesting habitats). There would be no impacts on other special status wildlife species.

4.8 CULTURAL RESOURCES

4.8.1 Compliance with Federal Regulations

Issue: How do the alternatives affect the preservation of cultural resources in Glen Canyon and Grand Canyon?

Impact Indicators:

- Erosion of terraces in Glen Canyon that support cultural resources
- Visitor effects on cultural resources
- Wind transport of sediment to protect resource-bearing terraces
- Flow effects on the Spencer Steamboat

The National Historic Preservation Act (NHPA) of 1966 (as amended) requires that federal agencies take into account the effects of their undertakings on historic properties. Historic properties are defined in the NHPA (16 U.S.C. 470w[5]) as any "prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion on, the *National Register of Historic Places*, including artifacts, records, and material remains related to such a property or resource." Cultural resources, in general, include archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties (TCPs), ethnographic resources, and museum collections. They also include locations and objects that are important for American Indian Tribes for maintaining their culture. (Other resources of importance to Tribes are addressed in Section 4.9.)

Based on the analysis of direct, indirect, and cumulative effects for this EIS, up to 220 historic properties have been identified that could be affected by the LTEMP. These historic properties fall within the Grand Canyon River Corridor and the Lees Ferry Lonely Dell Historic Districts discussed in Section 3.8 or the "rim-to-rim" TCP identified in Section 3.9.6. Most of these sites are situated on or within terraces located in the river corridor that are above the modern inundation zone, but that could receive windblown sediment from lower elevation areas that are regularly inundated by river flows or could be exposed by bank retreat or sediment depletion.

4.8.2 Analysis Methods

The alternatives being evaluated in this EIS differ in the way Glen Canyon Dam would be operated under each over the next 20 years. The resource goal for cultural resources is to maintain the integrity of *National Register*-eligible or listed cultural resources in place, where possible, with preservation methods employed on a site-specific basis. There is the potential for the alternatives to affect cultural resources along the river corridor downstream of Glen Canyon Dam via differing flow patterns or non-flow actions. This section focuses on two specific types of historic properties: archeological sites and historic districts; Section 4.9 focuses on other resources that are specifically important to Tribes. Section 4.9 also discusses other resources that are important to Tribes as contributing elements to their TCPs, but which may not qualify for listing on the *National Register* independently. The variables considered include direct flow effects (i.e., erosion of river margin sediments, deposition of sediments along the river margin, and inundation of sites), indirect effects (i.e., changes in the availability of sediment for redistribution by wind, erosion resulting from reduced sediment availability), and cumulative effects. The analysis relied on both quantitative and qualitative information to determine the potential effects of each of the alternatives. Three indicator metrics (1 in GCNRA and 2 in GCNP) were identified to describe the relative differences among the alternatives in order to evaluate the range of potential impacts on cultural resources.

For this analysis, cultural resources, as described in Section 3.8, that are potentially affected by Glen Canyon Dam operations are archeological resources (including historic and prehistoric structures and districts), TCPs, and ethnographic resources. While museum objects are defined as cultural resources, there are no effects or differences in effects on these classes of resources from the alternatives and will therefore not be discussed in the text. Impacts on cultural landscapes are not discussed separately, but any impacts on other resources (e.g., vegetation, wildlife, and sediment) are considered to have an effect on the landscape.

The physical attributes of cultural resources are nonrenewable and, if lost, irreplaceable. The primary concern is to minimize the loss or degradation of culturally significant material. Cultural resources analyzed within the Grand Canyon River Corridor Historic District and the Lees Ferry and Lonely Dell Ranch Historic District include artifact scatters, dwellings (both prehistoric and historic), resource collection areas, food preparation (roasting and food processing) activity areas, horticultural areas, and petroglyph and pictograph panels, collectively representing more than 12,000 years of human history.

Direct flow effects from releases from Glen Canyon Dam are most noticeable in the river reach immediately below the dam. This is primarily because this reach has little sediment input to help buffer the river terraces, and to a lesser degree because the affected resources are found in closer proximity to the Colorado River in this reach. In GCNP, most affected resources are located on terraces that are primarily affected indirectly by dam operations. Over time, flows and climatic conditions could affect the terraces on which archeological sites are located.

An indicator of flow effects that was considered in the analysis is the erosion of elevated terraces in the Glen Canyon reach, which was evaluated using a flow effects metric for Ninemile Terrace, because this site is a good proxy for similarly situated sites. In general, repeated inundation of the toe of a terrace could produce slumping of the terrace face, which could destroy or destabilize the cultural resources within or on the terrace deposits. The toe of Ninemile Terrace is estimated to be inundated when flows reach 23,200 cfs. The flow effects metric considered the frequency of when flows under the various alternatives reach levels that could create conditions that could result in terrace edge slumping and, ultimately, how they could affect the archeological sites within or on the terraces. The results of the metric were expressed as the number of days per year that the maximum daily flow would be >23,200 cfs under each alternative. See Appendix H for additional information on the flow effects metric.

Another historic property in the Lees Ferry and Lonely Dell Ranch Historic District of GCNRA, which was considered when assessing direct flow effects under the alternatives, is the Spencer Steamboat site, which lies within the Colorado River channel. Although the flow effects metric did not reveal any appreciable difference among alternatives in effect on the Spencer

Steamboat, impacts are still possible under the 20-year duration of the LTEMP from repeated exposure to high flows and repeating cycles of inundation and exposure. The wet-dry cycling resulting from fluctuations in lower flow levels contributes to the deterioration of structural elements. Flow levels that expose the steamboat also increase the potential for impacts from visitation and the accumulation of debris resulting in damage to fragile remains.

Visitor effects are frequently noted at many of the archeological sites along the river; these include the moving or theft of artifacts on archeological sites and the defacing of inscriptions, pictographs, and petroglyphs. A metric, visitor time off river, was developed to characterize how the various alternatives could influence the frequency at which archeological sites could be visited by people on river trips. The metric considered flow rates under the various alternatives during the summer months, when the number of visitors on the river is at its highest. The metric reflects the degree to which, due to the flows under an alternative, visitors would be able to spend more time exploring off of the river, which could result in more cultural resources being visited and possibly affected. See Appendix H for additional information on the time off river metric.

Erosion poses a threat to maintaining the condition of many of the archeological sites in both GCNRA and in GCNP. Any actions that help retain sediment are considered to have a potentially positive effect on maintaining the condition of archeological sites in the Canyons because they aid in maintaining the river corridor landscape and site stability. Most of the archeological sites along the Colorado River are located on terraces that represent the river terraces of the predam river system. Prior to construction of the dam, the terraces would have been directly affected by flooding on a 7–10 year return interval (Topping et al. 2003), and many contain flood deposits indicating they were flooded during or after occupation (see Schwartz et al. 1979; Bright Angel Site). The persistent removal of sediment from the system is a long-term effect on cultural resources resulting from the presence of the dam and will continue under all alternatives. Dam operations that decrease sediment-rich high flows, that increase the elevation and duration of low flows, and that promote the expansion of riparian vegetation all decrease sediment availability in the system for transport by wind (East et al. 2016). Sediment availability in the system for transport by the wind is therefore linked to alternatives that include more HFEs (which deposit sediment in locations that may allow for transport by the wind) and sediment retentive flows (East et al. 2016). Sediment availability in the system for transport by wind is also linked to alternatives that include longer duration low flows that expose bare, dry sand within the active river channel and make it available for windblown transport (East et al. 2016). Similarly, alternatives that reduce or reverse the expansion of riparian vegetation onto bare sand also increase sediment availability in the system for transport by wind (East et al. 2016). As discussed in Section 3.8, research has shown that sediment within the active river channel and/or deposited by HFEs can be transported by the wind to terraces and source-bordering aeolian deposits that contain historic properties (East et al. 2016). That wind-deposited sediment can help stabilize and preserve the archaeological properties in place (East et al. 2016). Sediment can also be removed from archaeological sites by wind and rain, factors that could lead to loss of integrity of a historic property (East et al. 2016; Collins et al. 2016). The actual extent to which current sediment levels can stabilize the archeological sites on the terraces remains unknown and would be determined through the LTEMP experimental period.

A wind transport of sediment index addresses the potential for sediment to be transported by the wind to the terraces along the river which contain hundreds of archeological sites. The metric reflects when conditions exist for movement of sediment by wind, and therefore the potential exists for cultural resources to receive sand and potentially be protected, under each alternative. Optimal conditions for wind transport of sediment occur when (1) fine sediment is deposited by flows above the stage of normal operations, and (2) low flows occur during the windy season (March–June), which exposes dry sand for potential redistribution by the wind. The metric used the sand load index and a flow factor which captures the frequency of low flows in the spring for each alternative. See Appendix H for additional information on the wind transport index. There would be a great deal of variability from site to site throughout the system with regard to the amount of sand deposited upwind by HFEs and the exposure of sediment at varying flows.

Another element incorporated into the alternatives is non-flow vegetation management efforts. All of the alternatives except for Alternative A incorporate non-flow vegetation management efforts (Section 4.6). Vegetation removal could increase erosion near an archeological site, or create more open sand upwind of an archaeological site, which could facilitate wind transport and deposition of sediment onto terraces and archaeological sites (East et al. 2016). The effect of non-flow vegetation management is not considered in the alternative-specific discussions because any vegetation management efforts would be coordinated with the cultural resources managers and would therefore not be anticipated to affect known cultural resources.

Each of the alternatives has the potential to affect cultural resources. These effects can be beneficial, meaning the alternative results in increased stability or preservation of cultural resources, or they can be adverse when an alternative results in destabilization of these resources. It is also possible that the alternatives would have no additional effect beyond those already occurring. The effects of alternatives could differ due to varying frequency, timing, and magnitude of daily flows, HFEs, and of the intervening flows between HFEs.

4.8.3 Summary of Impacts

Although the alternatives vary significantly in how water is released from Glen Canyon Dam within a year, the range of effects alternatives would have on cultural resources is expected to be minimal (Table 4.8-1), in part because annual water release volumes among alternatives would be nearly identical and cultural resources are dependent upon landform stability, a consideration that is primarily controlled by the amount of sediment in the system. The majority of cultural resources would not be inundated under any alternative, but some sites could experience indirect effects. Appendix H provides the results for each of the quantitative metrics considered in this analysis.

It has been noted that the potential for degradation of terrace stability at Ninemile Terrace is currently estimated to begin at 23,200 cfs when flows can begin to erode the toe of the terrace (Baker 2013). Erosion of the toe of a terrace can undermine the stability of the terrace and lead to slumping, as was noted after the 1996 HFE (Baker 2013), a 168-hr 45,000-cfs flow. This single

TABLE 4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen and Grand Canyons

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions regarding the slumping of terraces in Glen Canyon during HFEs (Glen Canyon flow effects index [GFEI] = 22.7); availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (wind transport of sediment index [WTSI] = 0.16); stability of Spencer Steamboat; and visitor time off river (time off river index [TORI] = 0.82).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (1.5% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (7.5% increase in WTSI); no change in stability of Spencer Steamboat or visitor time off river. Experimental hydropower improvement flows would increase the potential for slumping compared to Alternative A (1.6% increase in GFEI and decrease the availability of windblown sand (-9.5% decrease in WTSI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (4.4% decrease in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (137% increase in WTSI); negligible effect on stability of Spencer Steamboat or visitor time off river (<1% change in TORI).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (3.1% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (139% increase in WTSI); negligible effect on stability of Spencer Steamboat; decrease in visitor time off river (1.6% increase in TORI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (6.4% decrease in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (96% increase in WTSI); negligible effect on stability of Spencer Steamboat; decrease in visitor time off river (1.9% increase in TORI).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon due to sustained high flows in the spring (62% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (88% increase in WTSI); negligible effect on stability of Spencer Steamboat; increase in visitor time off river (8.9% decrease in TORI).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (8.7% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (193% increase in WTSI); negligible effect on stability of Spencer Steamboat; decrease in visitor time off river (2.1% increase in TORI).

TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Cultural Resources in Glen Canyon							
Erosion of terraces in Glen Canyon that support cultural resources (GCFEI)[a]	No change from current conditions which may contribute to slumping of terraces in Glen Canyon (GFEI = 22.7).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (1.5% increase in GFEI); experimental hydropower improvement flows would increase the potential for slumping (1.6% increase in GFEI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (4.4% decrease in GFEI)	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (3.1% increase in GFEI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (6.4% decrease in GFEI; lowest impact alternative).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon due to sustained high flows in the spring (62% increase in GFEI; highest impact alternative).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (8.7% increase in GFEI).
Spencer Steamboat	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended high flows on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.

TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Cultural Resources in the Grand Canyon							
Wind transport of sediment to high-elevation cultural resources (WTSI)[b]	Negligible influence on windblown sediment (WTSI = 0.16 out of 1); some benefit from HFEs until 2020 when HFEs are discontinued; potential adverse impact due to reduction in sediment availability after 2020 (highest impact alternative).	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (7.5% increase in WTSI); some benefit from HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (137% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (139% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (96% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (88% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (193% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period (lowest impact alternative).
Visitor effects on cultural resources (TORI)[c]	Negligible effect on visitor time off river (TORI = 0.82 out of 1).	Compared to Alternative A, no change in visitor time off river.	Compared to Alternative A, negligible change in visitor time off river (<1% change in TORI).	Compared to Alternative A, decrease in visitor time off river (1.6% increase in TORI).	Compared to Alternative A, decrease in visitor time off river (1.9% increase in TORI).	Compared to Alternative A, increase in visitor time off river (8.9% decrease in TORI) mostly resulting from high flows in spring (highest impact alternative).	Compared to Alternative A, decrease in visitor time off river (2.1% increase in TORI; lowest impact alternative).

Footnotes on next page.

TABLE 4.8-1 (Cont.)

[a] The Glen Canyon flow effects index (GFEI) represents the average number of days flows would be higher than 23,200 cfs during the 20-year LTEMP period. Higher values indicate a higher likelihood of slumping of terraces in Glen Canyon and greater impact on cultural resources that occur on those terraces. See Appendices B and H for a description of the index.

[b] The wind transport of sediment index (WTSI) is a 0 to 1 index that represents the potential for operations over the 20-year LTEMP period to provide conditions that are favorable for windblown transport of sediment to high-elevation terraces in the Grand Canyon that support archaeological sites. Any sand blown to these sites could reduce the erosion potential of those sites. A value of 0 indicates that there is no potential for windblown sediment transport (greatest impact); a value of 1 indicates that conditions are best for windblown sediment transport (lowest impact). See Appendices B and H for a description of the index.

[c] The time off river index (TORI) is a 0 to 1 index that represents the potential for operations over the 20-year LTEMP period to provide conditions that increase the amount of time whitewater rafters would have to explore nearby archaeological sites during the day. A value of 0 indicates that there is the greatest potential for time of river (greatest impact); a value of 1 indicates that there is the least potential for time off river (lowest impact). See Appendices B and H for a description of the index.

event demonstrated that terrace bank erosion may occur as flow elevations increase, during the period of peak high flow, and following the decrease of high flows to normal operational levels. Under most of the LTEMP alternatives, the greatest flows would be 45,000-cfs flows lasting for 96 hr (Section 4.3); these would be comparable to or less than flows that have occurred historically that resulted in slumping. The only alternatives in which this duration could be exceeded are Alternatives D and G. Alternatives D and G allow for longer duration HFEs (up to 250 and 336 hr, respectively) when there is adequate sediment. However, flows will reach the lower threshold of 23,200 cfs under all alternatives. Under most alternatives, HFEs would be limited in magnitude and duration, but the cumulative effect of more than one HFE in a year and in sequential years is not known, and could result in an even higher risk of slumping compared to the effects of individual HFEs.

The results from the Glen Canyon flow effects metric are shown in Figure 4.8-1. Alternative A most closely represents the current operational conditions. Under the metric, Alternative F would have the highest number of days per year; flows would be >23,200 cfs with an average of 14 days per year more than under Alternative A. Alternative F, therefore, has the highest potential for impacts on terraces that contain cultural resources in Glen Canyon. The higher number of days under Alternative F results from the relatively high spring flows between May and June (Section 2.3.6). The remaining alternatives have an average number of days per year where flows would be >23,200 cfs within 4 days of those under Alternative A.

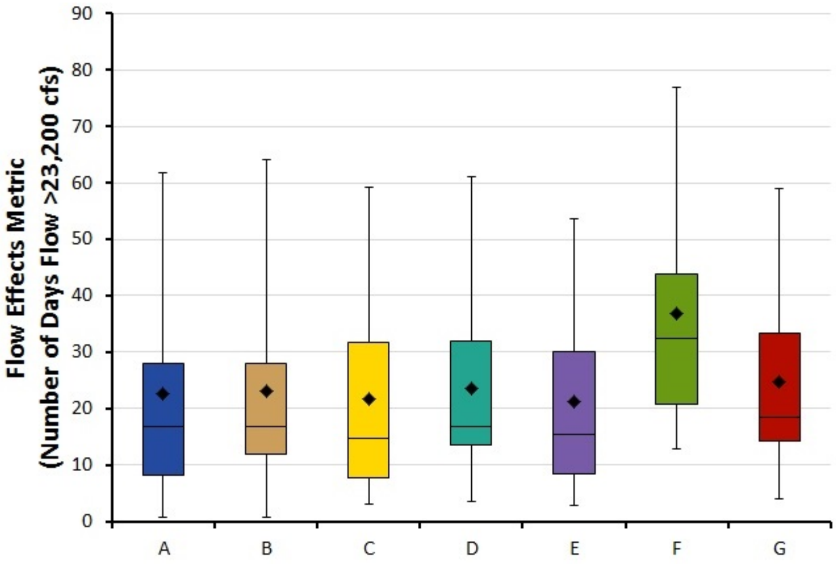

FIGURE 4.8-1 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives (letters). (Flows of this magnitude have the potential to affect cultural resources in Glen Canyon. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Although there are differences among alternatives in the number of HFEs, these differences have little effect on the number of days per year flows would be >23,200 cfs. This is because HFEs are relatively brief, and the large volume released under the HFE must be compensated for by releasing less water, which results in lower flows, at other times of year. Since all alternatives must release the same annual volume of water, alternatives with HFEs may have lower releases at other times of years than those without. The effect on the metric would be greater in years of high volume (≥10 maf) when equalization flows would be implemented according to the Interim Guidelines (Reclamation 2007a).

A persistent source of impacts on cultural resources is visitors (Bulletts et al. 2008, 2012; Jackson-Kelly et al. 2013). The effects being identified include the moving of artifacts on archaeological sites and the defacing of inscriptions, pictographs, and petroglyphs. The LTEMP does not incorporate any specific recommendations or policies concerning visitors under any alternatives. The Colorado River Management Plan (CRMP) is the primary document addressing visitor policies related to cultural resources in GCNP (NPS 2005a). Because LTEMP alternatives do not alter any policies concerning visitors, they do not differ with respect to any direct effect caused by visitors on cultural resources. Visitor effects are discussed under cumulative impacts.

An indirect effect related to visitor disturbances to cultural resources concerns the amount of time boaters have off river to explore and potentially interact with archaeological sites. More time would be available when flows are higher during the tourist season (June–September), and this factor could vary among alternatives. Analysis determined that the time off river index for most alternatives did not vary much (<2%) among current conditions (Alternative A). However, Alternative F has higher flows during May and June, so it could provide for more time off river during those months; these higher flows are offset by lower flows in July, August, and September, when time off river would be less than for other alternatives. Overall, the time off river index under Alternative F was lower (8.9% lower than Alternative A), indicating that visitors could spend more time off river than under Alternative A.

The Spencer Steamboat, located in GCNRA, could be directly affected by flows. The steamboat lies in the river, is part of the Lees Ferry/Lonely Dell Ranch National Historic District, and has been subject to all past dam releases, including HFEs (2012, 2013, and 2014), extended-duration HFEs (1996), low flows (2002), fall steady flows (2011–2013), and higher fluctuation flows (pre-1992). Although the site appears to be receiving an ongoing accumulation of sediment, which is beneficial for site preservation, ongoing monitoring has demonstrated that the wet-dry cycling resulting from fluctuations at low flow levels has caused the most obvious and persistent impacts on the site, as predicted by Carrell (1987). The recent installation of submerged monitoring stations (Pershern et al. 2014) will allow the opportunity to systematically evaluate the nature and origin of sediment accumulating at the site, and determine how that mechanism of transport may be influenced or affected by dam operations. Because the proposed flows do not exceed or vary greatly from past flows, similar effects are anticipated under any of the alternatives. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

The results from the wind transport of sediment index under the various alternatives are shown in Figure 4.8-2. This index represents the potential for wind to transport sand from channel-margin sandbars to high elevation terraces in the Grand Canyon, which could in turn reduce erosion and stabilize archaeological sites in these terraces. Historic properties contained within the Grand Canyon River Corridor Historic District are most susceptible to both aggregation and erosion of sand, which could create adverse or beneficial effects as explained in Section 4.8.2. Alternative G scores the highest of all the alternatives, with an average index value nearly three times greater than Alternative A. Alternative G has the highest number of HFEs and the lowest maximum daily flows during the windy months. Alternative G has parameters that are ideal for wind transport of fluvial sediment to terraces that contain cultural resources. The second highest scoring alternative is Alternative D. Alternatives A and B scored the lowest on this index.

On the whole, the wind transport of sediment index is highly correlated to the number of HFEs and the corresponding sand load index. The relationship between the sand load index and HFEs is discussed in Appendix E. The wind transport of sediment index is highly correlated to the sand load index because the average maximum discharge between March and June for each of the alternatives is within 5,000 cfs. With minimal difference in flow, the amount of sediment for distribution becomes the determining factor for the index. The exception to this is Alternative F. Although Alternative F was determined to have the second highest potential sand

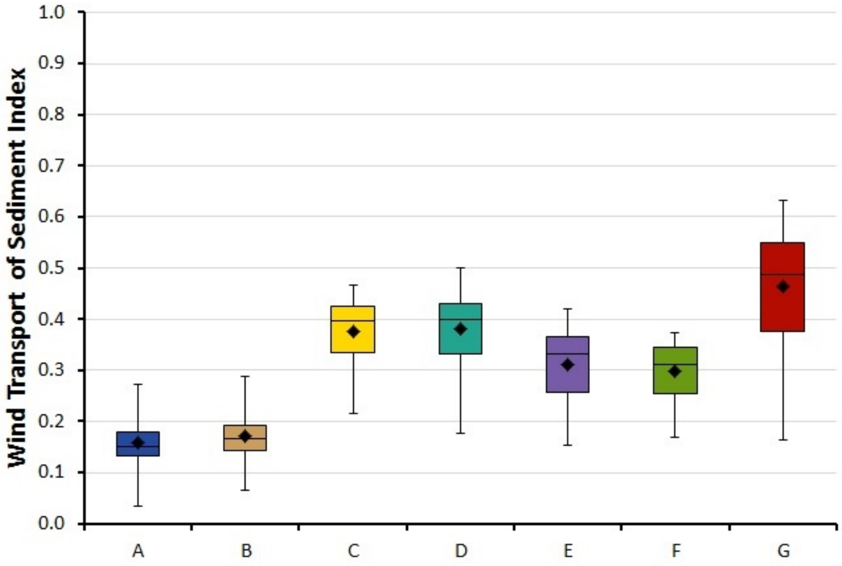

FIGURE 4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives (letters) (Values of 1 are considered optimal. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

deposition (second highest sand load index, only less than Alternative G), it ultimately has an average index value lower than Alternatives C, D, E, and G because larger discharges of water create less ideal conditions for wind transport.

4.8.4 Alternative-Specific Impacts

4.8.4.1 Alternative A (No Action Alternative)

Dam operations under Alternative A are expected to continue to contribute to conditions that could affect terraces that contain cultural resources in Glen Canyon. Observations in Glen Canyon noted that effects on the toe of the resource-bearing terrace at Ninemile Terrace begin with flows above 23,200 cfs (Baker 2013). Under Alternative A, flows could exceed 23,200 cfs and create conditions that could affect the stability of resource-bearing terraces. However, based on no significant deterioration of the Ninemile site since the 1996 flows, the effects of HFEs and interim operations on terraces in Glen Canyon under Alternative A would not be expected to change from current conditions. However, the cumulative effects of daily flows and the lack of sediment availability remain factors which could affect the stability of the terraces and continue to create the potential for effects as identified under the current MLFF operation. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, sandbar building that would result from HFEs under Alternative A could provide windblown sediment to high terraces; however, based on observations of existing conditions, this effect is expected to be small and would be reduced after HFEs were discontinued under this alternative in 2020. Alternative A is not expected to significantly improve the stability of archaeological sites.

In summary, operations under Alternative A could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under current conditions. Operations under Alternative A are not expected to significantly improve the stability of archaeological sites in the Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.2 Alternative B

Dam operations under Alternative B are not expected to have additional effects on terraces that contain cultural resources in Glen Canyon. Daily fluctuations under Alternative B would be higher than under Alternative A. In addition, experimental hydropower improvement flows under this alternative could result in daily flows of 25,000 cfs between December and February, as well as between June and August. However, these wider daily fluctuations are not expected to result in increased erosion rates because the alternative results in only a slight increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows >23,200 cfs) compared to Alternative A, which would result in a minor increase in the potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

It is anticipated that there will be some increase in the amount of sediment available for wind transport under Alternative B; both Alternatives A and B are expected to have approximately the same number of HFEs. Alternative B is expected to have a smaller beneficial effect from windblown sediment in the Grand Canyon relative to other alternatives that have more frequent HFEs. With hydropower improvement flows, there is expected to be a minor decrease with respect to wind transport compared to Alternative A.

In summary, operations under Alternative B could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under Alternative A. Operations under Alternative B are not expected to significantly improve the stability of archaeological sites in the Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.3 Alternative C

Dam operations under Alternative C are not expected to have any additional effects on terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative C would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was only observed after the 1996 HFE of 168 hr, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative C would not result in a substantial increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs; thus, there is no measurable difference in the potential for increased slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

The amount of sediment available for wind transport in the Grand Canyon under Alternative C is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention resulting from lower daily fluctuations, proactive spring HFEs in wet years, and reduced fluctuations before and after HFEs.

In summary, operations under Alternative C could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under Alternative A. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.4 Alternative D (Preferred Alternative)[21]

Dam operations under Alternative D could result in some additional destabilization of terraces that contain cultural resources in Glen Canyon. This could result from the extended-duration HFEs (up to 250 hr) that would be implemented as an experimental treatment in years when large inputs of sediment from the Paria River occur. No more than four extended-duration HFEs would be implemented during the LTEMP period under Alternative D. Some slumping was observed in Glen Canyon as a result of the 1996 HFE, which had a magnitude of 45,000 cfs and duration of 168 hr. In addition, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative D would result is a slight increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,300 cfs), which would result in a slightly increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative D is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention resulting from more even monthly release volumes, and proactive spring HFEs in wet years.

In summary, operations under Alternative D could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be a small decrease in the amout of time off river and subsequent effects on cultural resources, but no change from current conditions with respect to the stability of Spencer Steamboat.

4.8.4.5 Alternative E

Dam operations under Alternative E are not expected to have any additional effects on terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative E would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative E do not result in a substantial increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs),), which would result in no measurable difference in the potential for increased slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects

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[21] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on cultural resources.

of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative E is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period (although fewer than under Alternatives C, D, F, and G).

In summary, operations under Alternative E could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be negligible. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be a small decrease in the amout of time off river and subsequent effects on cultural resources, but no change from current conditions with respect to the stability of Spencer Steamboat.

4.8.4.6 Alternative F

Alternative F is expected to have additional effects on terraces that contain cultural resources in Glen Canyon because there would be an increase in the number of days when the bases of terraces in GCNRA would be inundated. Flows in May and June would be sustained at higher levels under this alternative, resulting in an increased number of days in wetter years when the bases of the terraces would be inundated, compared to Alternative A. Although HFEs would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the bases of terraces was only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative F would result in an increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs), which would result in an increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

Dam operations under Alternative F would allow faster travel times for boaters in May and June; therefore, boaters would have additional time off river to visit cultural resources during those months. This increase would be offset by the effects of lower flows in July–September. Alternative F is the only LTEMP alternative that, based on the analysis, could have any influence on visitor effects.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative F is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period and increased sediment retention from low steady flows throughout much of the year. However, the highest flows under Alternative F are in May, which reduces the potential for wind transport of sediment to terraces during this windy period.

In summary, operations under Alternative F could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat; there could be a small increase in the visitor time off river in May and June, which could result in increased visitation and potential damage to cultural resources.

4.8.4.7 Alternative G

Dam operations under Alternative G could result in some destabilization of terraces that contain cultural resources in Glen Canyon. This could result from the extended-duration HFEs (up to 336 hr) that would be implemented in years when large inputs of sediment from the Paria River occur. Some slumping was observed in Glen Canyon as a result of the 1996 HFE, which had a magnitude of 45,000 cfs and duration of 168 hr. In addition, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative G would result in an increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,300 cfs), which would result in an increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative G would be greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention from steady flows throughout the year, and proactive spring HFEs in wet years. Alternative G has the lowest spring operational flows when windy conditions are most typical. These factors create the best conditions under any of the alternatives for wind transport of sediment to the terraces.

In summary, operations under Alternative G could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be a small decrease in the amout of time off river and subsequent effects on cultural resources, but no change from current conditions with respect to the stability of Spencer Steamboat.

4.9 TRIBAL RESOURCES

Assessing the comparative impacts of the LTEMP alternatives on Tribal resources presents a challenge both because of the Tribes' holistic view of the Canyons, in which all things are interconnected, and because there is no single "Tribal view" held by all members of all Tribes. The holistic view encompasses most of the subject areas considered in this EIS and perspectives of the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes on these resources are found throughout the document.

The values placed by these Tribes on the river and its Canyons are significant and real but may be intangible; thus, they are not easily quantifiable. In addition, many of the values and resources most important to the Tribes are not directly affected by the proposed action as defined by operational patterns of water releases from Glen Canyon Dam.

Issue: How do alternatives affect Tribal resources in Glen, Marble, and Grand Canyons?

Impact Indicators:

- Health of the ecosystem including vegetation, wildlife, fish, and wetlands
- Water rights
- Condition of traditional cultural places

Issue: How do alternatives affect the sacred integrity of and Tribal connections to the Canyons?

Impact Indicators:

- Stewardship and educational opportunities
- Independent access to Canyons
- Number of nonnative fish removed each year
- Economic opportunity
- Incorporating traditional knowledge into the LTEMP EIS

4.9.1 Tribal Resource Goals

As discussed in Section 3.9, the Tribes that have the closest ties to the Canyons and are most actively involved in the LTEMP EIS process are the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes. Eight important themes or values relative to the Colorado River and its Canyons emerged from meetings, workshops, and webinars held with individual Tribal representatives and from reviewing ethnographies and Canyon monitoring reports produced by or for the Tribes. These have been identified as Tribal resource goals for the LTEMP EIS and grouped according to whether they can be represented quantitatively and whether they would be differentially affected by alternative management practices at or related to the operation of Glen Canyon Dam. An initial evaluation was made based on Tribal sources, and the Tribes were afforded the opportunity to review and provide input.

For this discussion, Tribal resources are divided into two categories: (1) traditional cultural places—those elements with fixed and defined locations, and (2) traditional cultural resources—resources that are either widely scattered or mobile, such as riparian vegetation, birds, mammals, and fishes. For many Tribes, resources in these two categories may be considered TCPs or contributing elements to a TCP and may be differently affected by flow and non-flow elements of the seven LTEMP alternatives.

4.9.1.1 Increase the Health of the Ecosystem in Glen, Marble, and Grand Canyons

Tribes such as the Hopi express their perception of the state of the Canyons in terms of the Canyons' health (Yeatts and Huisinga 2003, 2006, 2009, 2010, 2011, 2012, 2013). For the Hopi, natural elements and resources are significant for creating a culturally significant, harmonious landscape. Without them, the landscape would not be whole. These resources, because they are either widely scattered or mobile, rather than existing in a fixed location, may be considered traditional cultural resources.

In general, the affected Tribes are concerned with the state of the Canyons as a whole. The determination of Canyon health from a Tribal point of view can be complex and can vary from Tribe to Tribe. For example, a recent survey of Hopi Canyon monitors showed that most respondents found the Canyons to be in good health, or at least better taken care of than in the past, in part because of Hopi participation in the adaptive management process by monitoring important sites such as the salt mine, and because of the offerings made in the Canyons by Tribal members (Yeatts and Huisinga 2013). Some aspects of Canyon health are quantifiable and parallel or reflect values that have been expressed by the Tribes or their representatives. These include riparian plant diversity, wetland abundance, and characteristics of native fish populations considered here. The interest of the Tribes extends beyond these measures to impacts on other aspects of Canyon health explored elsewhere in this chapter, including natural processes (Section 4.4), aquatic ecology (Section 4.5), vegetation (Section 4.6), wildlife (Section 4.7), hydropower (Section 4.13), and environmental justice (Section 4.14).

The Western concept of ecosystem has much in common with the Tribes' view of their place in an interconnected natural world. Plant communities form a fundamental aspect of any ecosystem, and vegetation health is an indicator of ecosystem health. Metrics for vegetation community diversity and wetland abundance in the riparian zone most directly affected by flow management at the Glen Canyon Dam have been developed based on the results of an existing state and transition model developed by GCMRC for Colorado River riparian vegetation downstream of Glen Canyon Dam; this is described by Ralston et al. (2014) and in Appendix G and discussed in Section 4.6.1. The metrics are on a scale relative to starting conditions where a higher value means greater vegetation community diversity or wetland abundance relative to starting conditions.

A healthy ecosystem from a Tribal perspective is characterized by a high degree of species diversity, represented here by diversity in vegetation community types. The model projects transitions over the 20-year LTEMP period for each alternative analyzed. During discussions with the Tribes, they often expressed their view that all forms of life have value, whether native or nonnative. To take this perspective into account, evaluation of diversity included nonnative (primarily tamarisk) as well as native vegetation, including the invasive arrowweed. The analysis indicated that all alternatives on average would result in a decrease in total vegetation diversity over the 20-year LTEMP period.

The loss in diversity would be greatest under Alternatives C, F, and G. Under these alternatives, the acreage occupied by the invasive tamarisk increases (Table 4.9-1). Alternatives under which tamarisk[22] would increase are characterized by spring high flows (HFEs or ≥30 days with flows >20,000 cfs), which serve to distribute seed, followed by low flows in the growing season (May–September) which would allow seedlings to establish themselves. Alternative B results in the least loss of diversity, followed by Alternatives A, D, and E. Under these alternatives, the area covered by tamarisk decreases.

Another indicator of Canyon health is the abundance of wetlands in the riparian zone. Although they make up only a small part of the riparian area of the river corridor (4.6 acres, or 0.5% of total area of all vegetation types), wetlands include plants of medicinal and cultural significance to some Tribes (Jackson et al. 2001) that continue to be harvested with care (Yeatts and Huisinga 2006). The Hopi generally see the marshes as healthy and well taken care of, but there is some indication in the Tribal monitoring reports that cattail and reed marshes are decreasing in size and number and that cattails are decreasing in number (Yeatts and Huisinga 2013).

TABLE 4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover

Alternative	Mean Diversity Score[a]	Change in Tamarisk Cover (ac)
A	0.95	−58.4
B	0.97	−71.3
C	0.75	104.0
D	0.94	−22.4
E	0.93	−45.7
F	0.70	230.7
G	0.83	46.4

[a] Higher values of diversity indicate better condition relative to other alternatives. A value less than 1 indicates an expected reduction in diversity relative to current conditions over the 20-year LTEMP period. A value greater than 1 indicates an expected increase in diversity.

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[22] The model takes into account the effects of scouring, drowning, desiccation, and sediment deposition, but does not account for the effects of the tamarisk leaf beetle or tamarisk weevil. These two insect species are expected to result in a reduction in the amount of live tamarisk in the river corridor.

Based on the vegetation models discussed in Section 4.6, the change in abundance was determined for each of the wetland community types (common reed wet marsh and willow/baccharis/horsetail wetland). Wetlands would expand under hydrologic regimes that lack extended periods of high flows (≥30 days with maximum daily flows >20,000 cfs) and extended low flows (≥30 days with maximum daily flows <10,000 cfs), but are maintained with occasional extended high flows (in many cases) or HFEs and an absence of extended low flows during the growing season. Alternatives that include frequent extended low flows, such as the annual flows for Alternative F, or extended high flows followed by extended low flows tend to result in transitions of wetlands to other plant community types. All of the alternatives are expected to result in a decrease in wetland cover, with particularly large decreases under Alternative F.

The state of aquatic life in the Canyons is discussed in Section 4.5. Section 4.5.2 presents a summary of projected impacts on native and nonnative fishes and the aquatic food base. These projections correlate well with recent results from the Hopi monitoring program, which found the native fish populations in the Canyons, particularly the humpback chub, to be healthy (Yeatts and Huisinga 2013).

Impacts on riparian and terrestrial wildlife are discussed in Section 4.7.2. Impacts on indicators of wildlife and habitat health are expected to be limited, with no major differences among the alternatives. Alterations in riparian vegetation and the aquatic food base are not expected to be sufficient to adversely affect amphibians and reptiles over the long term; however, alternatives could produce changes in near-shore aquatic and wetland habitats that are important to amphibians and that serve as important food production areas for both amphibians and reptiles (Section 4.7.2.2). The distribution of woody riparian vegetation is not expected to vary enough under any alternative to disrupt the migration of riparian bird species or to have noticeable differences in impacts on species that nest in riparian vegetation; however, alternatives could produce changes in shoreline habitats that could affect waterfowl and wading birds (Section 4.7.2.3). Impacts on mammals such as muskrat and beaver would be negligible under all alternatives (Section 4.7.2.4). Larger mammals such as deer and bighorn sheep are mobile and able to adjust their use of different habitats along the corridor. Impacts on bighorn sheep under all alternatives are expected to be negligible (Section 4.7.2.4). A recent Hopi monitoring report found birds, mammals, insects, and snakes in the Canyons all to be healthy (Yeatts and Huisinga 2013).

4.9.1.2 Protect and Preserve Sites of Cultural Importance

Sites of cultural importance to the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes include archaeological sites, places associated with traditional narratives of Tribal identity, rock writing, sacred places, offering sites, springs, and traditional resource collection areas. Individually or collectively, these may be referred to as traditional cultural places. These places may also be contributing elements to a TCP such as the "rim-to-rim" TCP described in Section 3.9.6.

Expected effects of the alternatives on archaeological sites and historic properties are discussed in Section 4.8. Other cultural resources associated with specific locations are likely to experience the same types of impacts as those on archaeological sites. Those Tribes that regularly monitor the condition of culturally important sites and resources in the Canyons most often list intentional and unintentional damage to sites from visitors to the Canyons as the prime threat to site integrity. Reported damage includes trailing, trampling, removal of vegetation, disturbance of artifacts, vandalism, and disruption of the sacred context through inappropriate behavior (Section 4.9.1.4). Bank erosion and inundation are mentioned less frequently in the monitoring reports. The majority of visitors to the river corridor arrive by boat. Higher flows have faster currents, so boaters travel more quickly between campsites, leaving more time to explore off-river, which could lead to more visitation of cultural sites and a greater potential for damage. Modeling of visitor time off the river indicates that there is almost no difference in expected amount of time off river among the LTEMP alternatives, with the exception of Alternative F. Under this alternative, boaters could spend slightly more time off the river in May and June when flows are relatively high and steady. Overall, impacts on these sites of importance are not expected to vary significantly as a result of visitation among the alternatives.

For the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes, all water is sacred and the places where it emerges from the ground as seeps and springs are particularly sacred. Tribal members travel to sacred springs in the Canyons to retrieve water for ritual use in their own communities (Dongoske 2011b; Jackson-Kelly et al. 2013). Warm mineral springs, such as Pumpkin Springs, are sacred and their waters are considered therapeutic (Austin et al. 2007). The Tribes are concerned with the purity of these sacred waters and exercise stewardship over them, which can include appropriate prayers and offerings at the springs and along sacred trails that lead to them. The Hopi largely consider the springs to be healthy, as a result of their having access to the springs and being able to perform appropriate stewardship activities (Yeatts and Huisinga 2009). Occasionally, spring sources, such as Pumpkin Springs, may take on a murky, polluted appearance and an HFE is welcome in order to flush out the muck and algae that have accumulated. This may disrupt access for a short amount of time, but water levels return to normal within a few weeks. During consultation, the Tribes that monitor Tribal resources in the Canyons—Hopi, Hualapai, Navajo, Southern Paiute, and Zuni—all have expressed more concern with damage to the springs and disrespect for the sanctity of the waters by non-Tribal visitors to the Canyons than with inundation resulting from flow management. Hopi monitoring reports suggest that the health of the springs is largely unaffected by the operation of Glen Canyon Dam. Overall, adverse impacts on springs and seeps from operation of Glen Canyon Dam are expected to be negligible, while the HFEs have some benefit.

Some adverse impacts can be mitigated through education and communication. All of the Tribes with ties to the Canyons are affiliates of Native Voices on the Colorado River (https://nativevoicesonthecolorado.wordpress.com), and many have their own outreach programs developed to educate visitors to the Canyons regarding Tribal histories and affiliations with the Canyons. This is discussed further in Section 4.9.1.4. Mitigation of potential effects on resources of Tribal concern will be subject to ongoing consultation.

4.9.1.3 Preserve and Enhance Respect for Canyon Life

For those Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements without which its sacredness would not be complete. The Zuni, in particular, have established a lasting familial relationship with all aquatic life in the Colorado River and the other water sources in the Canyons (Dongoske 2011a). They consider the taking of life through the mechanical removal of trout to be offensive, and to have dangerous consequences for the Zuni. The confluence of the Colorado River and the Little Colorado River is considered a sacred area because of its proximity to places identified in traditional Tribal narratives as the locations of the Zuni and the Hopi emergence into this world and other important events. The killing of fish in proximity to sacred places of emergence is considered desecration, and would have an adverse effect on the Grand Canyon as a Zuni TCP. In addition, Pueblo of Zuni have identified significant social and psychological effects to their community during mechanical removal periods. For example, between 2003 and 2006, when the initial mechanical removal efforts occurred at the confluence of the Little Colorado and Colorado Rivers, the Zuni reported an increase in the use of taser guns by Zuni police on Zuni community members. The Zuni view this as a direct adverse effect on the Zuni community from mechanical removal events (Panteah 2016). The Zuni expressed their view on this subject in Section 3.9.6. In the past, the Zuni have expressed a willingness to consult with Reclamation in good faith in “seeking and reaching agreement with the Zuni to avoid, reduce, compensate for, or otherwise mitigate any adverse effects” (Zuni Tribal Council 2010).

Reclamation and the NPS are committed to continue to consult with the Tribes regarding nonnative fish control. Reclamation committed in agreements with Tribes in 2012 to consider live removal when feasible (Reclamation 2012b); however, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters. Reclamation and the NPS have worked with the Tribes to determine a beneficial use of the removed fish on other projects and understand that what is considered beneficial use may not be the same for all Tribes. Reclamation and the NPS are committed to consult further with the Tribes to determine acceptable mitigation for nonnative fish control.

The purpose of trout management activities is to enhance the survival of the endangered humpback chub by reducing the numbers of trout in the river. Reducing the trout population would reduce competition with and predation on young-of-the-year chub near the confluence with the Little Colorado River from trout moving downstream from reaches just below Glen Canyon Dam (Section 4.5). Two forms of trout management have been proposed: TMFs and mechanical removal. Each is being considered as a management action that may be triggered when trout and/or chub populations are at specified levels. Trout management is included in all alternatives except Alternative F, and mechanical removal is only possible under Alternative A until 2020 (see Appendix J).

A TMF is a highly variable flow pattern of water releases at Glen Canyon Dam intended to control the number of young-of-the-year trout in the Glen Canyon reach of the Colorado River and, subsequently, the migration of trout to downstream areas such as the confluence of the Little Colorado River (Chapter 2). A typical TMF would consist of several days at a relatively high sustained flow (e.g., 20,000 cfs) that would prompt young fish to move into the shallows along the channel margins and, depending on the time of year, would prompt spawning fish to construct redds and lay eggs in nearshore shallow areas. The high flows would be followed by a rapid drop to a low flow (e.g., 5,000 cfs), stranding young-of-the-year trout and, depending on the time of year, possibly exposing the eggs, thus preventing them from hatching. With the exception of Alternatives C and D, under which TMFs could be implemented early in the LTEMP period even if not triggered by predicted high trout recruitment, TMFs may be triggered during years in which trout recruitment in the Glen Canyon reach is anticipated to be high. Under each of the alternatives in which TMFs are included, they would initially be conducted as experiments; they would be implemented only if they prove to be successful in reducing the trout population in the Glen Canyon reach. In general, TMFs would most likely be triggered when spring HFEs, which can stimulate the food base and thus trout production, are followed by relatively high steady summer flows. Where the number of HFEs is limited, as in Alternative B, it is expected that TMFs would be triggered in fewer years. Modeling indicates TMFs would be triggered most often under Alternative G. If TMFs prove successful, they would reduce the number of times mechanical removal would be triggered.

Mechanical removal would employ electrofishing to stun and remove nonnative fish. Usually, the removed fish would then be euthanized and put to some beneficial use. For example, in one mechanical removal test, the trout were emulsified and used as fertilizer in the Hualapai Tribal gardens (Reclamation 2011a). In their Comprehensive Fisheries Management Plan, the NPS committed to put all removed nonnative fish (including trout) to beneficial use through human consumption (NPS 2013e). GCMRC has modeled the number of years in which mechanical removal would be triggered under various alternatives. In general, mechanical removal would be triggered in far fewer years than TMFs. In general, when TMFs are projected to be triggered in more years, mechanical removal of trout would be triggered in fewer years. Modeling indicates that under Alternative G (the alternative under which the most TMFs would be triggered), mechanical removal would never be triggered in more than 7 years out of 20.

With regard to fish management, the Tribes have expressed a preference for letting nature take its course rather than intervening to mitigate the consequences of past actions. For example, the Zuni have suggested that it could be that the emergence of whirling disease in trout is nature’s way of tempering out-of-balance fish dynamics. The Zuni and Hopi have questioned the trout’s level of impact on the humpback chub population and have urged additional studies of this relationship before undertaking the large-scale removal of fish (Zuni Tribal Council 2010; Yeatts and Huisinga 2013). For them, TMFs and mechanical removal are both offensive and would be considered an adverse effect on the Grand Canyon TCP. Likewise, the Hopi Tribe “recommends that efforts to understand what are the limiting factors for the humpback chub (both habitat issues in mainstem and Little Colorado River, and the life stage(s) where mortality rate is limiting) continue to be a focus of aquatic research. In addition, management actions such as the translocation should be continued as long as they are continuing to be successful” (Yeatts and Huisinga 2012).

4.9.1.4 Preserve and Enhance the Sacred Integrity of Glen, Marble, and Grand Canyons

The preservation of the sacred integrity of the Canyons is vitally important to the Tribes. Under the provisions of Executive Order 13007, both Reclamation and the NPS have obligations to accommodate access to and ceremonial use of Indian sacred sites by Indian religious practitioners; to avoid adversely affecting the physical integrity of sacred sites; and to maintain the confidentiality of the location of sacred sites as requested by the Tribes. Inappropriate behaviors and activities within the Canyons can negatively affect the sanctity of the Canyons. Visitor impacts noted by Tribes include, but are not limited to, trampling of resources, lack of respect for sacred sites, trailing, illegal collection of artifacts, artifact movement, vandalism, and littering. Disruptive, boisterous behavior in the Canyons disturbs the spiritual ambiance that surrounds sacred trails and sites. Many Tribes have reported experiencing discomfort when performing ceremonies at certain sites within the river corridor because of the number and behavior of visitors present. In some cases, Tribal members have been approached by curious visitors during private ceremonies (Bulletts et al. 2008. 2012; Jackson-Kelly et al. 2013). During consultation meetings, Tribal representatives expressed concerns regarding integrity of the Canyons. For example, the Zuni expressed that from their perspective, any impact on the Canyons is an impact on the Zuni people, because the spirits that are disturbed can bring adverse consequences to the Zuni and their families; and the Navajo indicated that they have observed a reduction in the strength of plants gathered from sites along the river to be used for medicinal and ceremonial purposes, and have sought out other collection sites. In addition, visitor impacts could diminish the feeling, association, settings, and materials of important places, aspects used to evaluate the integrity of a traditional cultural place.

Non-Tribal visitors will continue to be present under all alternatives. As noted in Section 4.8, Alternative F is modeled to result in slightly more visitor time off-river, resulting in slightly more risk to sacred sites than the other alternatives. There is very little variation in the modeled time off river among the other alternatives

Possible adverse effects on sacred sites that result from tourists in the Canyons could be mitigated and in some cases prevented through communication and education. All of the Tribes with historical and cultural ties to the Canyons are affiliates of Native Voices on the Colorado River, an educational program that offers the Tribes a chance to share their historic and contemporary perspectives of the Colorado River and the Canyons with river guides, river outfitters, and the public. River guides and outfitters in turn share this information with their clients on river trips (NVCR undated). In addition, some Tribes have developed their own outreach programs. The Southern Paiute Consortium has developed outreach programs with Colorado River guides, local schools and universities, and civic organizations. When they are conducting monitoring trips or present in the corridor, the consortium also talks with Canyon visitors. The goal of the program is to educate non-Tribal members about the Southern Paiute history and broad cultural landscape of the Canyons (Bulletts et al. 2012). The Hualapai encourage public outreach and education as a means of teaching people about negative impacts on Hualapai resources (Jackson-Kelly et al. 2013). The Zuni have expressed interest in developing an educational program that would allow Zuni cultural advisors to inform river guides, boatmen, NPS, and Reclamation about the importance of Zuni history and traditional issues as they are related to the Canyons (Dongoske 2011a). Reclamation and NPS are committed to continue working with the Tribes to develop or continue development of education and outreach programs. It is important that visitors to the Canyons understand the magnitude of the consequences their presence has on Tribal resources and Tribal members.

4.9.1.5 Maintain and Enhance Healthy Stewardship Opportunities and Maintain and Enhance Tribal Connections to the Canyons

During the development of the LTEMP DEIS, the Tribes expressed concern with maintaining and improving their connection to the Canyons, including the stewardship responsibilities given to them at creation or emergence. Stewardship is partly expressed through their participation in the Glen Canyon Dam Adaptive Management Work Group (AMWG) and Technical Work Group (TWG), which encourage participation in an open discussion of issues related to the operation of Glen Canyon Dam as well as the design of monitoring and research conducted by the GCMRC.

The Tribes regard maintaining their connection to the Canyon through traditional activities and fulfilling their stewardship responsibilities as vital. Tribal stewardship takes place on many levels, including participation in the management of Canyon resources through monitoring programs, ceremonial activities, and recounting oral histories. These stewardship activities are important for all Tribal members, but they are particularly important for passing down traditions and oral histories to Tribal youth. As discussed above, insensitive behavior by Canyon visitors and researchers may disrupt the Tribes' ritual activities of stewardship and passing cultural values connected to the Canyons to the next generation (Bulletts et al. 2008, 2012; Jackson-Kelly et al. 2013).

Adverse effects can be avoided or mitigated through continued communication; this includes communicating about the timing and duration of HFEs. Many of the Tribes are members of both the AMWG and TWG. Many Tribes also have their own monitoring programs whereby resources and sites of importance are monitored, the health of the Canyon is examined, sacred sites are visited, and respects are paid to the Canyon and its resources. Continued communication and collaboration between the Tribes and federal agencies will enhance stewardship opportunities for the Tribes, as will maintaining the Tribes' continued access to the Canyons to conduct important religious practices necessary for continued stewardship.

4.9.1.6 Economic Opportunity

As discussed in Section 4.14.2.1, economic ventures currently operated by the Tribes and Tribal members rely heavily on tourism both in and around the Canyons. These ventures include commercial rafting on the river, tourist facilities in or near the Canyons, and vendors of Native American crafts, such as jewelry, basketry, and ceramics, that rely heavily on trade with tourists. Within the Canyons, the Grand Canyon Resort Corporation, owned by the Hualapai Tribe, provides recreational facilities including river running below Diamond Creek. The Hualapai River Runners provide day and overnight whitewater rafting trips, and flat-water day trips. The

Tribe (working with GCNP) also issues some permits for private whitewater boating below Diamond Creek. The 1-day whitewater boating trips create the largest river recreation economic impacts within the Canyons (61 jobs and $1.4 million in annual regional income), while day-use flat-water trips also make a significant contribution (19 jobs and $0.4 million in annual regional income). The NPS CRMP (NPS 2006b), developed in consultation with the Hualapai Tribe, places limits on the number and size of trips below Diamond Creek. There are a fixed number of river trip launches allowed under the NPS plan and more demand than capacity. The number of trips would not change as a result of any of the alternatives, so the impacts on the river runners would be the same as Alternative A for all alternatives. The same annual economic impacts would be expected under each of the alternatives.

The Havasupai, Hualapai, and Navajo all operate land-based tourist facilities in or adjacent to the Canyons that are important contributors to their economic development. The Havasupai operate a lodge, café, trading post, and campground on their reservation, and offer Canyon tours. The Hualapai have a number of tourist and recreational facilities and opportunities including a river running operation, skywalk, helicopter rides, and hiking in the Western Grand Canyon. The Navajo have Tribal parks overlooking the Little Colorado River and Grand Canyon, and along Lake Powell. No difference in tourist use of land-based facilities or Native American craft vendors is expected among the LTEMP alternatives. However, Tribes have expressed the desire for communication before and during HFEs to enable them to communicate information to tourists as necessary.

The Navajo also operate the Antelope Point Marina on Lake Powell. Direct and indirect economic impacts of visitation to Lake Powell facilities are discussed in Section 4.14.2.1. There is very little difference among the alternatives regarding impacts on marinas on Lake Powell. Models indicate that all alternatives except Alternative F would result in negligible change in regional income, less than 0.6%. The largest potential decrease would be 1.1% under Alternative F because that alternative has higher releases in the spring and lower releases through the summer every year, and consequently slightly different reservoir levels in the summer months.

4.9.1.7 Maintain Tribal Water Rights and Supply

Reclamation is committed to operating Glen Canyon Dam so that all water obligations are met, including those to Tribes. Lake Powell supplies water to both the Navajo Chapter of LeChee and the City of Page, Arizona, which share a water intake system (NPS 2009b). Currently, two intakes provide water. There is an intake on the face of the dam at 3,480 ft above mean sea level and a second intake off the penstocks to Units 7 and 8 at 3,470 ft above mean sea level. In the current configuration, the minimum pool elevation necessary to supply LeChee and Page is 3,470 ft above mean sea level. The minimum power pool elevation is 3,490 ft above mean sea level, well above the water intakes (Grantz 2014). Plans now under consideration call for a new, lower intake at 3,373 ft above mean sea level. The modeling results for all of the alternatives show Lake Powell levels remaining above the existing and proposed intakes for the entire 20-year period (see Appendix J). The lowest pool level projected is 3,480.3 ft above mean sea level, about the level of the intake on the dam face and 10 ft above the penstock intake.

4.9.1.8 LTEMP Process

Tribes have been involved in the LTEMP development process and will continue to be involved in the implementation of LTEMP. Tribes have routinely expressed concern regarding how LTEMP decisions are made rather than what decision is made, the genuine incorporation of Tribal input, and the importance of learning to improve management over time. They have favored an experimental approach resulting in adaptive management.

Over the course of the development of the LTEMP DEIS, Reclamation and the NPS have sought to incorporate Tribal input into the LTEMP process. Cooperating and consulting Tribes were included in Cooperating Agency and stakeholder meetings. Reclamation and NPS have also held Tribal meetings, workshops, conference calls, and webinars. Various documents related to the development of the LTEMP DEIS have been provided to the Tribes for their review and input. When requested, there have been face-to-face meetings with the Tribes. Tribes were given the opportunity to contribute to the Tribal lands, affected environment, and environmental consequence sections of the EIS, and Tribal views have been incorporated throughout this EIS. A complete summary of Tribal consultation efforts is provided in Section 5 and Appendix N.

4.9.2 Analysis Methods

Two main issues emerged in analyzing how the proposed action would be likely to affect Tribal resources in the Canyons: (1) How would alternatives affect the continued existence of Tribal resources in the Canyons? and (2) How would alternatives affect the sacred integrity of and Tribal connections to the Canyons? Since the Tribes are the best judges of how the alternatives would affect them and because some Tribal resources are sacred and their locations confidential, the answers to these questions require input from the Tribes. The analysis presented here is based mainly on input from the Tribes, augmented with analysis of quantifiable impacts.

Input from the Tribes was sought and continues to be sought in a number of ways. Initially, NPS and Reclamation identified 43 federally recognized Tribes with potential historical and cultural ties to the Colorado River and its Canyons and invited them to participate in the LTEMP EIS process, as either Cooperating Agencies or consulting parties. NPS and Reclamation conducted meetings with groups of cooperating and consulting Tribes; these meetings included workshops, teleconferences, webinars, and face-to-face meetings with Tribal authorities in efforts to fully identify Tribal concerns about impacts of alternatives on resources. The agencies also consulted with Tribes during Cooperating Agency meetings. Tribes that chose to become Cooperating Agencies also were given the opportunity to contribute to the writing of the EIS. Chapter 5 and Appendix N provide descriptions and other information for the consultation process. Goals for resources of Tribal concern were developed from information obtained at these meetings, and Tribes had an opportunity to review, edit, and contribute additional information and concerns. Where possible, potential impacts on these resource goals were determined quantitatively, and modeling was used to quantify impacts. Modeling and analysis incorporated analyses from other resource areas such as aquatic resources, riparian vegetation, and economics. Tribes were invited to meetings where the results of the modeling were presented, and they were given a chance to ask questions and contribute comments.

Qualitative assessments of impacts were based on written information produced by or for the Tribes. Significant insight into Tribal priorities came from the Tribes that regularly monitor the state of resources in the Canyons that they consider significant. Tribal monitoring reports from the Hopi (Yeatts and Brod 1996; Dongoske 2001; Yeatts and Huisinga 2006, 2009, 2010, 2011, 2012, 2013), Hualapai (Jackson et al. 2001; Jackson-Kelly et al. 2009, 2010, 2011, 2013), Navajo (NNHPD 2012), Southern Paiute (Austin et al. 1999; Drye et al. 2000, 2001, 2002, 2006; Bulletts et al. 2003, 2004, 2008, 2010, 2011, 2012; Snow et al. 2007), and Zuni (Dongoske 2011a) were consulted for information on sites and resources of importance, as were ethnographies produced for the Tribes during previous related National Environmental Policy Act of 1969, as amended (NEPA) analyses (Ferguson and Lotenberg 1998; Lomaomvaya et al. 2001; Roberts et al. 1995; Yeatts and Huisinga 2003; Stoffle et al. 1994, 1995; Hart 1995).

4.9.3 Summary of Impacts

A summary of the impacts of the LTEMP alternatives on Tribal resources is presented in Table 4.9-2. In general, it is anticipated that there will be limited impacts on places and resources from the proposed action and the impacts that are anticipated do not vary greatly among the alternatives. Flow-related impacts on traditional cultural places include inundation by high flows (i.e., flows above the normal maximum operating flow of 25,000 cfs), resulting in erosion and temporary loss of access to such features as springs. Inundation impacts are temporary and can be mitigated through communication between Reclamation and the Tribes regarding scheduled high flows. The potential for the inundation of historic properties and erosion of terraces where historic properties are located is discussed above in Section 4.8. It is anticipated that traditional cultural resources most directly affected by flows would be riparian vegetation and fishes. Flow impacts on culturally important terrestrial wildlife would be minimal and do not vary among alternatives (see Section 4.7).

Some alternatives include non-flow actions that include trout removal and vegetation management. Proposed experimental vegetation management activities include the removal of nonnative species, clearing vegetation to expose sand for camping and distribution by wind, removing encroaching vegetation from campsites, and replacing removed nonnative species with native species, many of which have cultural importance to the Tribes. Vegetation management has the potential for both beneficial and adverse impacts (see Section 4.9.4). Increasing campable area by clearing campsites may not be seen as positive by Tribes that consider the Canyons a sacred space and are concerned with visitors disrespecting and interfering with important ceremonial and other cultural activities. All LTEMP alternatives would have the same overall level of visitation, set by the number of permits, so effects would be negligible in terms of a difference from No Action. In addition, there are potential positive effects that could result from using plants as barriers, closing off trails to culturally sensitive sites, and increasing native plants in treatment areas that are important to Tribes. Removing vegetation to open up sandy beaches has the potential for allowing wind to transport fine sediment to higher elevations and potentially shielding archaeological sites from erosion. These impacts would not vary among the action alternatives. Lethal removal of trout has been identified by the Zuni with the support of other affiliated Tribes as having an adverse effect on the TCP of the Grand Canyon, particularly when

TABLE 4.9-2 Summary of Impacts of LTEMP Alternatives on Tribal Resources

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Operations would result in no change in the amount of sand available for wind transport to cultural resource sites; a negligible loss of riparian diversity; a small loss of wetlands and no impact to Tribal water and economic resources. No TMFs, but mechanical trout removal could be triggered. After 2020, potential adverse impact to culturally important archaeological sites.	Compared to Alternative A, operations would result in a slight increase in the amount of sand available for wind transport to cultural resource sites except during hydropower improvement flows when there would be a slight decrease. There would be a slight loss in riparian diversity and slightly more loss in wetlands. There would be no impact on Tribal water and economic resources. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the second largest loss in wetlands and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the least amount of wetlands loss across alternatives; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could occur with or without triggers. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; an increase in wetlands loss; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites but would result in an increase in the potential for river runners to explore and potentially damage places of cultural importance during May and June. The greatest loss of wetlands, largest increase in invasive species, and lowest riparian plan diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs or mechanical trout removal. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in the greatest potential increase in the amount of sand available for wind transport to cultural resource sites; the third-largest wetlands loss across alternatives; and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Places							
Visitation of culturally significant sites	No change in the potential for recreationists to visit culturally significant sites	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, slight increase in the potential for recreationists to visit culturally significant sites in May and June.	Same as Alternative A.
Availability of sand for wind transport to protect culturally important archaeological sites	Negligible change in wind transport of sand; some increase in sand from HFEs until 2020, when HFEs are discontinued; potential adverse impact due to reduction in sediment availability after 2020.	Compared to Alternative A, slight potential increase (+7%) from HFEs continuing over entire LTEMP period; slight decrease (−10%) with implementation of hydropower improvement flows.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+137%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to protect cultural resource sites (+139%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+96%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+88%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+193%), resulting from increase in frequency of HFEs.

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Resources							
Riparian plant diversity	Slight loss of riparian plant diversity (0.95 diversity index).	Similar to Alternative A (0.97 diversity index).	Compared to Alternative A, decrease in riparian plant diversity (0.75 diversity index).	Similar to Alternative A (0.96 diversity index).	Similar to Alternative A (0.93 diversity index).	Compared to Alternative A, lowest riparian plant diversity (0.70 diversity index); largest acreage of invasive plants.	Compared to Alternative A, decrease in riparian plant diversity compared to Alternative A (0.83 diversity index).
Retention of wetlands (existing marsh is less than 5 ac total)	Approximately 3.6 ac retained; 28% loss.	Compared to Alternative A, approximately 4 ac retained (8% more). Under hydropower improvement, flows wetlands loss would be greater.	Compared to Alternative A, approximately 1.25 ac retained (47% less). Second-largest area of wetlands loss across alternatives.	Compared to Alternative A, approximately 4.2 ac retained (12% more). Least loss of wetlands across alternatives.	Compared to Alternative A, approximately 3.1 ac retained (10% less).	Compared to Alternative A, approximately 0.7 ac retained (58% less). Largest area of wetlands loss across alternatives.	Compared to Alternative A, approximately 1.5 ac retained (30% less). Third-largest area of wetlands loss.
Frequency of TMFs	No TMFs.	TMFs expected in 3 of 20 years	TMFs expected in about 6 of 20 years.	TMFs expected in 8 of 20 years.	TMFs expected in 3 of 20 years.	No TMFs.	TMFs expected in 11 of 20 years. Most TMFs of any alternative.
Frequency of mechanical removal of trout	Trout removal expected in <1 of 20 years.	Trout removal expected in <1 of 20 years.	Trout removal expected in about 0–3 of 20 years.	Trout removal expected in about 2–3 of 20 years.	Trout removal expected in about 0–2 of 20 years.	No trout removal. Least trout removal of any alternative.	Trout removal expected in 3 of 20 years. Most trout removal of any alternative.
Impacts on culturally important wildlife	Negligible adverse impact effects on culturally important wildlife.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Economic and Water Resources							
Impact on Tribal recreation operations in Western Grand Canyon	No change from current sediment conditions; facilities may be affected by HFEs until 2020.	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; slightly greater impacts on docks due to slightly more frequent HFEs.	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.	Compared to Alternative A, potential for small increase (<2%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.[a]	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.	Compared to Alternative A, potential for small increase (6%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to most frequent HFEs.	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.
Impact on Tribal land-based vendors	No impact on land-based vendors.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Impact on Tribal marina operators	No change from current condition.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, slight decrease in marina visitation (1.1%).	Same as Alternative A.
Water supply	Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

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[a] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended duration fall HFE. The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition (1.3 fewer), and this reduction in frequency could reduce the impacts on Hualapai docks under Alternative D.

it takes place in proximity to the confluence of the Colorado River and the Little Colorado River, an area of special significance to the Zuni (Dongoske 2011b), the Hopi (Yeatts and Huisinga 2013), and the Navajo (Roberts et al. 1995). The lethal mechanical removal of trout and/or TMFs would be considered a significant adverse impact by some Tribes; however, if done in conjunction with mandated consultation with the Tribes, the impact may be reduced through beneficial uses and other practices that have been used for the Bright Angel fish removal efforts. For a discussion of alternative specific impacts see Section 4.9.4.

As discussed in Section 3.9, many of the Tribes that have been involved with this EIS consider portions of the Colorado River and its tributaries, the Canyons through which they flow, as well as elements within the river and Canyon corridors, as a TCP or part of a TCP. Any impact on any cultural place or cultural resource—be it an archaeological site, sacred place, traditional collection area, important plant or animal, or other element considered a TCP or contributing element to a TCP—is also considered an impact on the TCP, because these resources add to the overall traditional value of the TCP for these Tribes. As previously discussed, many Tribes have their own monitoring programs whereby resources and sites of importance are monitored, the health of the Canyon is examined, sacred sites are visited, and respects are paid to the Canyon and its resources. Any effect on the Canyons and their resources will likely be evaluated by each Tribe during the monitoring assessments. The Zuni in particular have stated that any action within the Grand Canyon will have to be assessed by the Zuni people for adverse effects that may be experienced in the Zuni Pueblo itself.

The Hualapai Tribe operates recreational facilities in the Western Grand Canyon, and their facilities and activities could be adversely affected by operation of Glen Cayon Dam. The Hualapai have expressed concern over dam operations they believe are increasing the amount of sediment collecting in the channel in their operational area below Diamond Creek. Their primary operations are centered in and around the Quartermaster area (RM 260). They have reported adverse impacts on their commercial operations from river sediment, including effects on equipment, access to their docks, and navigation in the river.

The Hualapai are concerned over the steep and unstable slopes previously inundated by Lake Mead that are now exposed due to reservoir levels retreating from the previous high-water line. The issues associated with the steep and unstable shorelines in the Lake Mead delta are related to the declining reservoir level, and will not be resolved until the level of Lake Mead either regains its previous high levels or until the banks naturally stabilize under new, lower reservoir levels.

The Hualapai are concerned with the effect of different flows on their boat docks. The number and duration of HFEs under LTEMP alternatives could affect boat docks and other facilities operated by the Hualapai Tribe. The dock structures were evaluated in 2012 by Reclamation engineers (Walkoviak 2012; see Section 4.10.2.6 for a discussion of the findings of this evaluation). LTEMP alternatives differ in the frequency and type of HFEs that would occur over the 20-year LTEMP period (Table 4.3-1; Sections 4.3.2 and 4.3.3). Alternative A would have the fewest (average of 5.5 HFEs over the LTEMP period, with HFEs not being conducted after 2020); Alternative F would have the most (average of 38.1 HFEs over the entire LTEMP period).

It is expected that dam operations, HFEs, equalization flows, and other flow events will continue to deliver sediment to the Western Grand Canyon and Lake Mead. Nearly all sediment that enters the Grand Canyon below Lake Powell will eventually move downstream. Higher flows, in general, do transport more sediment, and sediment transport will continue in the free-flowing portions of the river below Diamond Creek. Based on the analysis presented in Section 4.10.2.6, the increase in suspended sand at RM 225 under LTEMP alternatives relative to Alternative A is approximately 6% for Alternative F, 2% for Alternative D, and less than 3% for all other alternatives. This difference is significantly less than the differences under potential future hydrologic conditions. The location where this suspended sand deposits downstream of RM 225 will be a function of Lake Mead elevation and local hydraulic conditions. However, the amount will not be more that what is in suspension, so the sand deposition at RM 260 will be much less than the 2 to 6% increase in suspended sand expected under the LTEMP action alternatives.

4.9.4 Alternative-Specific Impacts

This section presents the impacts of the LTEMP alternatives on the Tribal resource goals presented in Section 4.9.1. Impacts are based on both quantitative and qualitative indicators of the status of resources that Tribes have indicated are culturally important. Factors considered include the state of riparian plant communities, riparian and terrestrial wildlife, and aquatic resources. Also considered are the time Canyon visitors spend off the river, potentially impacting traditional cultural places and economic opportunities for commercial Tribal river runners.

4.9.4.1 Alternative A (No Action Alternative)

Under Alternative A, the No Action Alternative, the modified fluctuating flows as defined in the 1996 ROD for the operation of Glen Canyon Dam would continue. Existing operations and recent decisions would be maintained. The existing HFE protocol and nonnative fish control actions and experimentation would continue until 2020 as specified in existing EAs. The HFE protocol EA (Reclamation 2011b) projected that access to and use of certain cultural properties could possibly be altered due to inundation in the area directly affected by an HFE. Less sand would be moved from Marble Canyon downstream under this alternative than under any other and it has the lowest sand load index score, which suggests there would be less building of sandbars, resulting in less sand being available for windborne transport to culturally important sites.

Alternative A is likely to result in a relatively even proportional distribution of plant community types, but a slight loss in plant community diversity. Modeling results suggest that 3.6 ac of wetland habitat will remain at the end of the 20-year LTEMP period, a decrease of 28% from the current wetland acreage (Section 4.6). An estimated 4.6 ac of wetlands occurs downstream from the dam.

Testing of TMFs is allowed under Alternative A, but since there has not been a decision to implement these flows, they are not considered a regular action under this alternative. Modeling of trout numbers suggests that mechanical removal trips would only rarely be triggered, resulting in the fewest removal trips of any alternative where mechanical removal is allowed, in part because removal actions would expire in 2020. As indicated by lack of significant changes in the riparian plant communities and the mobility of larger animals, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and would not differ among the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

No change from current conditions is expected with regard to recreational economic or water supply impacts on Tribes. There would be no change in current sediment conditions that could affect Hualapai recreation operations in the Western Grand Canyon, but existing Hualapai docks could be affected by HFEs until 2020. The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be no effect on the Navajo marina under this alternative (Sections 4.2 and 4.14.2.1; Reclamation 2011a). Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative A, there would be a relatively even distribution of plant community types, but a slight loss in plant diversity and wetland acreage. Trout removal trips are expected to be triggered in 1 year out of 20, the lowest expected number of trips among alternatives, which represents no change from current conditions. The availability of sand for wind transport could provide some benefit to some places of traditional cultural importance due to HFEs until 2020 when the HFE protocol expires, at which point these areas could experience an adverse impact due to lack of available sediment for wind transport. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal recreation economics, Tribal land-based vendors, marinas operated by Tribal enterprises, or Navajo Nation water supply. Any impact on a Tribally important cultural place or resource is also considered an impact on a Tribe's TCP.

4.9.4.2 Alternative B

Alternative B would follow the same monthly water release volumes as Alternative A, but there would be greater fluctuations in 10 months of the year and increased down-ramp rates. Under this alternative, HFEs would be implemented over the entire 20-year LTEMP period, but they are limited to no more than one every other year. There is greater daily flow fluctuation than in Alternative A for most months. Hydropower improvement flows—operations with wider fluctuations in high electrical demand months—would be tested in 4 years when the annual release volume is ≥8.23 maf. TMFs would be tested and implemented if successful.

This alternative is likely to result in the maintenance of current levels of evenness and diversity of plant community distribution; slightly higher plant diversity is expected than under Alternative A. Due to a lack of extended high or low flows that scour or desiccate wetlands, approximately 4 ac of wetlands would be retained under Alternative B, 8% more than under Alternative A (Section 4.6), except under the hydropower improvement flows, in which case there would be increased loss of wetlands. An estimated 4.6 ac of wetlands occurs downstream from the dam.

The wider daily fluctuations under Alternative B would reduce the potential for bar-building, making less sand available for windborne transport to culturally important places relative to normal operations under Alternative B. Under typical operations, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be slightly greater (+7%) than under Alternative A, unless hydropower improvement flows are included, in which case the sand load index would be slightly less than under Alternative A (−10%).

Under this alternative, TMFs are expected to occur in about three of the 20 LTEMP years. This alternative and Alternative E likely would have the fewest TMFs among the alternatives that would test and implement TMFs (Alternative A allows testing and Alternative F does not). Low numbers of TMFs result from lower numbers of trout recruits in the Glen Canyon reach. Low trout numbers result from higher daily fluctuations and fewer spring HFEs. When trout numbers are low, mechanical removal is triggered in fewer years.

Based on the lack of significant changes in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as big horn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (see Section 4.8.3).

Few changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<3%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon. Existing Hualapai docks could be affected by HFEs during the entire LTEMP period, but the total number of HFEs (7.2) would be comparable to the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be no effect on reservoir elevation and the Navajo marina under this alternative. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative B, current wetland acreage is expected to be retained and plant diversity would be slightly higher than under Alternative A, except under hydropower improvement flows, which would result in greater loss of wetlands. TMFs are expected to be triggered in 3 years out of 20; while trout removal trips are expected to potentially be triggered, if at all, in 1 year out of 20. The availability of sand for wind transport to potentially protect some places of traditional cultural importance would somewhat increase relative to Alternative A because HFEs would occur over the entire LTEMP period. However, the high fluctuations of hydropower improvement flow would potentially decrease the availability of sand. Places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts to Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors, marinas operated by Tribal enterprises, or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to a minor increase in the number of HFEs over the LTEMP period. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.3 Alternative C

Under Alternative C, the highest water release volumes would occur in the high electric demand months of December, January, and July, with lower volumes from August through November to conserve sediment inputs during the monsoon period. The HFE protocol would be followed for the entire 20-year period, and some additional HFEs would be allowed. Proactive spring HFEs would be tested in years with a high volume of flow (>10 maf). Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+137%), making more sand available for windborne transport to cultural sites (Section 4.3).

Operations under this alternative are expected to result in relatively low plant community diversity and evenness. High flows followed by growing season lows are likely to result in more loss of diversity than under Alternative A (Section 4.6). This alternative is expected to retain approximately 1.25 ac of wetlands, 47% less than that retained under Alternative A. This alternative results in more wetland loss than any other alternative except Alternative F. An estimated 4.6 ac of wetlands occurs downstream from the dam.

TMFs are expected to be triggered in about 6 out of 20 years under this alternative because of the relatively higher number of trout expected to be produced (Section 4.5). Mechanical trout removal is expected to be triggered in few if any of the 20 years modeled.

As under other alternatives, because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (see Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small increase (<3%) in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon. Existing Hualapai docks could be affected by HFEs during the entire LTEMP period, and the total number of HFEs (21.3) would be higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative C, the diversity of riparian plant communities is expected to decrease, and this alternative is expected to result in the second-largest area of wetland loss when compared to Alternative A. TMFs are expected to be triggered in 6 out of 20 years, and trout removal trips could potentially to be triggered in 3 out of 20. Under Alternative C, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for an increase in impacts on Hualapai docks related to a minor increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Economic effects on Tribal tourist enterprises would be the same as under Alternative A, except for Tribally operated marinas, which would experience a negligible drop in income. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.4 Alternative D (Preferred Alternative)

Alternative D adopts characteristics of Alternatives C and E to achieve sediment retention characteristics and other resource benefits while reducing impacts on the value of hydropower generation and capacity, when compared to Alternatives C and E. Like Alternatives C and E, Alternative D includes a number of condition-dependent flow and non-flow actions that may be triggered by resource conditions. Alternative D differs from the other two in the specific trigger conditions and the actions that would be taken. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+139%), making more sand available for windborne transport to cultural sites (Section 4.3).

Under Alternative D, riparian plant community diversity and evenness would be virtually the same as under Alternative A and similar to Alternative E. These alternatives would result in only a slight loss of plant community diversity. There would be on average an overall loss of invasive species; both tamarisk and arrowweed would decrease under Alternative D. There would be somewhat less loss of tamarisk under Alternative D than under Alternatives A or E. Repeated extended high flows can remove tamarisk and arrowweed. The low number of growing season extended low flows would limit tamarisk establishment and the shifting of wetland communities to arrowweed (Section 4.6.3.4).

Approximately 4.2 ac of wetlands would be retained under Alternative D, 12% more than under Alternative A. This alternative would result in the least amount of wetland loss of all alternatives. Greater wetland acreage is associated with greater plant community diversity. Low numbers of extended low flows during the growing season would limit the occurrence of wetland communities shifting to arrowweed. An estimated 4.6 ac of wetlands occurs downstream from the dam.

Spring HFEs, which stimulate the food base, and steady summer flows are factors that tend to result in trout population growth. Spring HFEs would be more common under Alternative D than under Alternative A, and summer daily fluctuations would be slightly less under Alternative D than under Alternative A. Under Alternative D, TMFs are expected to be triggered in about 8 out of 20 years. This would be more often than under any alternative except Alternative G, partly because TMFs could be triggered during years in which the production of young-of-the-year rainbow trout in the Glen Canyon reach is anticipated to be high. Overall, because TMFs are expected to reduce the number of fish in the trigger reach, mechanical removal could be triggered in fewer years. Under Alternative D, modeling suggests that trout removal would occur in about 2 to 3 out of 20 years.

As under other alternatives, because of the types of changes expected in riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<2%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon; existing Hualapai docks could be affected by HFEs during the entire LTEMP period, and the total number of HFEs (21.1)[23] would be higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative D, there would be a relatively even distribution of plant community types, but a slight loss in plant diversity, similar to Alternative A. The least amount of wetland acreage loss would occur under this alternative. TMFs are expected to be triggered in 8 years out of 20, and trout removal trips could potentially be triggered 3 years out of 20. Under Alternative D, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.5 Alternative E

Like Alternatives C and D, Alternative E includes a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions. Alternative E differs from the other two in the specific trigger conditions and the actions that would be taken. Under Alternative E, the relatively high number of HFEs projected would result in a higher sand load

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[23] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs could reduce the impact of Alternative D on Hualapai docks in the Western Grand Canyon.

index (+96%) and significantly more sandbar building potential than under Alternative A, making more sand available for windborne dispersal to culturally important places.

This alternative would result in a slightly less diverse and even distribution of plant community types than under Alternatives A, B, and D, but more diversity and evenness than under Alternatives C, F, or G. This alternative is expected to retain approximately 3.1 ac of wetlands, 10% less relative to Alternative A. An estimated 4.6 ac of wetlands occurs downstream from the dam.

TMFs would be triggered in about the same number of years as under Alternative B. Fewer TMFs are expected because the number of trout in the Glen Canyon reach is expected to be lower under this alternative as a result of higher summer fluctuation levels and fewer spring HFEs. Mechanical removal would be triggered in up to 2 out of 20 years.

Because of the types of changes expected in riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<3%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon. Existing Hualapai docks could be affected by HFEs during the entire LTEMP period, and the total number of HFEs (17.1) would be higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative E, diversity and evenness of plant community types would be slightly less than under Alternatives A, B, and D, but slightly more than under Alternatives C, F, or G. This alternative would retain more wetland acreage than Alternatives F, G, and C. TMFs are expected to be triggered in 3 years out of 20, and trout removal trips could potentially to be triggered 2 years out of 20. Under Alternative E, there is a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change in the potential for recreationists to visit culturally significant sites. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.6 Alternative F

Alternative F is designed to re-create a more natural (pre-dam) flow pattern while limiting sediment transport and providing lower, stable base flows in summer, fall, and winter, and warmer temperatures in the summer. It allows both spring and fall HFEs, which should significantly increase the deposition and retention of sediment relative to Alternative A. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+88%), making more sand available for windborne transport to cultural sites (Section 4.3).

This alternative would result in the lowest degree of evenness and diversity and the greatest spread of tamarisk-dominated communities. This alternative would have high flows that spread tamarisk seeds followed by growing season low flows, which would allow seedlings to establish themselves. Similarly, this alternative is expected to result in the greatest amount of wetland loss of any alternative, retaining only 0.7 ac of wetlands, 58% less than under Alternative A. An estimated 4.6 ac of wetlands occurs downstream from the dam.

This alternative includes neither mechanical removal nor TMFs and would thus allow nature to take its course regarding the interaction of humpback chub and nonnative trout. The steady flows and frequent spring HFEs of this alternative are expected to produce larger numbers of trout relative to most other alternatives.

Because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Under this alternative, visitors to the Canyons would spend slightly more time off the river than under any of the other alternatives (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<6%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon; existing Hualapai docks could be affected by HFEs during the entire LTEMP although the total number of HFEs (38.1; highest of alternatives) would be much higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (1.1%; highest of alternatives) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative F, plant diversity would be at its lowest, wetland loss would be at its highest, and the largest acreage of invasive species would occur. There would be no TMFs or mechanical trout removal trips under this alternative. Under Alternative F, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be a slight increase in the potential for recreationists to visit and potentially damage culturally significant sites during May and June. Impacts to Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.7 Alternative G

Alternative G targets the conservation of sediment through steady, equal monthly release volumes that would maximize retention of sediment, and the largest number of HFEs of any alternative, some with extended duration, which would distribute and retain sediment at higher elevations. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+193%), making more sand available for windborne transport to cultural sites (Section 4.3).

With more high flows, it is likely that this alternative would result in somewhat less diversity and evenness of plant communities than under Alternative A, but more diversity and evenness than under Alternatives C and F. The alternative would retain approximately 1.5 ac of wetlands, 30% less than Alternative A. Mean wetland acreage would be lower that of Alternatives A, B, D, and E, but above that of Alternatives C and F (see Appendix J). An estimated 4.6 ac of wetlands occurs downstream from the dam.

The steady summer flows and spring HFEs that characterized this alternative create favorable conditions for the growth of the trout population. As a consequence, TMFs are expected to occur more often under this alternative (11 out of 20 years) than under any other. Mechanical removal would also occur more often under this alternative than any other, on average about 3 out of 20 years.

Because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<3%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon; existing Hualapai docks could be affected by HFEs during the entire LTEMP although the total number of HFEs (24.5) would be much higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative G, there would be a decrease in riparian plant diversity, and the third-largest wetland acreage loss across alternatives would occur. TMFs are expected to be triggered in 11 out of 20 years, and trout removal trips could potentially to be triggered 3 out of 20 years. Under Alternative G, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change in the potential for recreationists to visit culturally significant sites when compared to Alternative A. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.10 RECREATION, VISITOR USE, AND EXPERIENCE

This section presents the potential impacts of LTEMP alternatives on recreation, visitor use, and experience. Background information on the resources or resource attributes included in this analysis can be found in Section 3.10. There are also references to Sections 4.5 (Aquatic Ecology), Section 4.6 (Plant Communities), Section 4.14 (Socioeconomics and Environmental Justice), and the Recreation Economic Analysis in Appendix L, as they apply to visitor use and experience.

Issue: How do the alternatives affect recreation, visitor use, and experience?

Impact Indicators:

- Fish size and catch rate
- Flow fluctuation, water levels, and HFEs
- Navigability and safety
- Lost visitor opportunities
- Camping and recreation facilities on old sediment terraces
- Campsite area
- Campsite crowding
- Encounters with other groups
- Lake recreation
- Impacts on Tribal recreation operations in the Western Grand Canyon

4.10.1 Analysis Methods

The analysis of impacts on recreation, visitor use, and experience downstream of Glen Canyon Dam was based on assessment of alternative-specific differences in 10 indicators that were based on six quantitative metrics developed using recreational findings in published papers and reports, and quantified based on alternative-specific flow characteristics. The metrics were developed through consultation with subject matter experts and with consideration of comments from Cooperating Agencies.

Four of the metrics address issues important to visitor use and experience in GCNP, while the other two metrics focus on the Glen Canyon reach between the dam and Lees Ferry. Some information used for the assessment is not from measures of specific factors but is qualitative in nature. Most metrics were created as indices with values ranging from 0 to 1, where 1 is the optimal condition for that resource, and 0 represents the lowest possible value. An index with a relative scale was used because it was often impossible to quantify the condition of the resource, but it was possible to generate a relative scale that reflected that condition. For example, there is no current methodology that defines how specific camping areas in GCNP might respond to HFEs, but there is a basis for making conclusions about which conditions are likely to favor a general increase in camping area in the park. The exception to the 0 to 1 scale is the Glen Canyon Rafting Metric, which measures the number of potential lost rafting trips. All of the metrics except the Glen Canyon Rafting Metric are seasonally weighted to reflect seasonal differences in recreational use, with more weight given to conditions in the peak recreation period than in periods with less use. More information including assumptions and limitations of these metrics is in Appendix J. The six recreation-specific metrics are as follows:

- *Camping Area Index*—Accounts for optimal campsite area building and maintenance flows and sediment load (also used as input to the assessment of campsite crowding).

- *Time Off-River Index*—Relates the level of flows to visitors being able to spend time ashore visiting attractions.

- *Fluctuation Index*—Based on combinations of flows and fluctuations identified as preferable by experienced boat operators.

- *Navigation Index*—Based on the percentage of time minimum daily flows are less than 8,000 cfs (also used as input to the assessment of campsite crowding and encounters with other groups).

- *Glen Canyon Rafting Metric*—Estimates the number of visitors unable to participate in day rafting in Glen Canyon due to high flows; the metric is the mean annual number of lost visitor opportunities.

- *Glen Canyon Inundation Index*—Accounts for flows that impact recreational sites and recreational uses within the Glen Canyon reach.

An 8,000-cfs maximum daily fluctuation limit was established in the 1996 ROD (Reclamation 2006) to address safety, recreation, and sediment concerns (Reclamation 1995). The analysis conducted for the LTEMP EIS has not identified new evidence to suggest that these concerns and this fluctuation level do not still apply. The determination of 8,000 cfs as a maximum daily fluctuation level that is suitable for recreation was based on Bishop et al. (1995). Bishop et al. surveyed both the river guides and the general public regarding preferences, and the river guides reported a preference for a maximum of 8,000-cfs daily change for a "tolerable recreation experience" under relatively high average daily flows. The current river guide community and the public have continued to state the preference for retaining the 8,000-cfs maximum daily fluctuation that is currently in place under Alternative A.

In the discussions below, the anticipated impacts of the alternatives are compared to the effects of Alternative A, the No Action Alternative. Impacts on recreation were developed using these metrics as well as published literature to evaluate how recreation would be affected by the alternatives. Information used includes the number and seasonality of HFEs, daily flow information, economic analysis, and fishery and vegetation management information that is documented in other portions of this EIS. Metric values are based on 20-year simulations of Glen Canyon Dam releases under different hydrology and sediment conditions as determined for the various LTEMP alternatives.

The economic analysis conducted by Gaston et al. (2015) quantified the net economic use value (NEV) of recreation at Lakes Powell and Mead, and for three reaches of the Colorado River: Glen Canyon, the Upper Grand Canyon, and the Lower Grand Canyon under the LTEMP alternatives. The results of this analysis are presented in Section 4.14 and Appendix L.

4.10.2 Summary of Impacts

The impacts of LTEMP alternatives on visitor use and experience are summarized in Table 4.10-1. Graphs showing the performance of the alternatives for each of the metrics are shown in Figure 4.10-1. A more detailed analysis for each of the alternatives is presented in Section 4.10.3.

Differences in the alternatives' effects on recreation tend to be mostly related to differences in the frequency and characteristics of experimental flows, particularly HFEs and TMFs, but are also related to differences in operations such as fluctuating flow effects during high-demand seasons for hydropower. Effects are greater for actions that occur during peak recreational use months, for example certain spring HFEs that may occur during the peak rafting season. Some experimental flows and actions occur in only a few years; thus, for the majority of time, the LTEMP alternatives' experimental flows cause little difference for recreation effects. Differences in daily maximum and minimum flows under normal operations can, however, distinguish between alternatives with respect to potential effects on recreation. Daily maximum flows above 8,000 cfs increasingly reduce usable beach area, and would effectively submerge all beach area at flows above 31,500 cfs (Section J.2.1.1). In addition, daily fluctuations resulting in minimum flows below 8,000 cfs can affect river navigability and cause delays at rapids. Flow fluctuations can also affect shoreline angling, and rafters who camp may be forced to move to higher ground and to check boat moorings overnight. Such effects would not occur or would be less prominent under alternatives with reduced fluctuation or steady flows (e.g., Alternatives A, C, D, F, and G), while high steady flows under Alternative F in some spring and summer months would reduce usable camping area. Lastly, not all effects are experienced by all recreational users, and other effects are localized. For example, flow fluctuations may affect overnight boaters who camp more than day-only boaters, while vegetation management and mechanical trout removal are both localized actions that would affect recreation in only portions of the river at any given time.

4.10.2.1 Glen Canyon Fishing

Effects of Flow Fluctuations, Water Levels, and HFEs

Anglers in the Glen Canyon reach identified a preference for steady flows and flows between 8,000 and 15,000 cfs (Bishop et al. 1987). Stewart et al.'s (2000) follow-up of the Bishop et al. (1987) study after the implementation of MLFF flows in 1996 did not identify river level fluctuations as an issue, and in 2011 an AZGFD creel study found that angler satisfaction in the Glen Canyon reach was high (Anderson, M. 2012), indicating that the existing flow regime was favorable for Glen Canyon anglers.

TABLE 4.10-1 Summary of Impacts of LTEMP Alternatives on Recreation, Visitor Use, and Experience

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, few lost day-rafting visitor days (49 over 20-year period), and declining camping area.	Compared to Alternative A, comparable number of HFEs and higher fluctuations result in more lost day-rafting visitor days (45% increase) in Glen Canyon, highest number of large trout (13% increase), lowest trout catch rates, most navigability concerns, and similar camping area (5% increase in index).	Compared to Alternative A, more HFEs and lower fluctuations result in more lost day-rafting visitor days in Glen Canyon (543% increase), similar number of large trout (3% decrease), higher trout catch rates; fewer navigation concerns, and more camping area (170% increase in index).	Compared to Alternative A, more HFEs and comparable fluctuations result in more lost day-rafting visitor days in Glen Canyon (610% increase), similar number of large trout (5% increase), similar trout catch rates, similar navigation concerns, and more camping area (158% increase in index).	Compared to Alternative A, more HFEs, higher fluctuations, and more frequent flows below 8,000 cfs result in more lost day-rafting visitor days in Glen Canyon (261% increase), more large trout (8% increase), lower trout catch rates, more navigation concerns, and more camping area (118% increase in index).	Compared to Alternative A and all other alternatives ,frequent HFEs, steady flows, and lack of trout management actions result in most lost day-rafting visitor days in Glen Canyon (1,776% increase), higher trout catch rates, but fewest large trout (22% decrease); very few navigability concerns, and more camping area (191% increase in index).	Compared to Alternative A, more HFEs and steady flows result in few additional lost day-rafting visitor days in Glen Canyon (4% increase), higher trout catch rates, but fewer large trout (9% decrease); very few navigability concerns, and greatest potential increase in camping area (220% increase in index).

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Glen Canyon—Fishing							
Fluctuations, water levels, and HFEs	No change from current conditions; high angler satisfaction with flow levels and daily fluctuations; average 5.5 HFEs (lowest of alternatives) until 2020 (up to 8 days in a calendar year if both spring and fall HFEs were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 7.2 HFEs over LTEMP period (up to 4 days in a calendar year) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 21.3 HFEs over LTEMP period (up to 10 days in a calendar year if both a spring and an extended-duration fall HFE were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 21.1 HFEs over LTEMP period (up to 10 days in a calendar year if an extended-duration fall HFE were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 17.1 HFEs over LTEMP period (up to 8 days in a calendar year if both spring and fall HFEs were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, lower satisfaction with flow levels; average 38.1 HFEs (highest of alternatives) over LTEMP period (up to 8 days in a calendar year if both spring and fall HFEs were triggered) may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow rates; average 24.5 HFEs over LTEMP period (up to 18 days in a calendar year if both spring and extended-duration fall HFEs were triggered) that may disrupt fishing during their implementation.
Fish size and catch rate	No change from current conditions; intermediate catch rates and estimated 770 large trout (≥16 in.).	Compared to Alternative A, lowest angler catch rates, but 13% more large trout (870, most of any alternative).	Compared to Alternative A, slightly higher catch rates; 3% fewer large trout (750).	Compared to Alternative A, similar catch rates; 5% more large trout (810).	Compared to Alternative A, similar catch rate; 8% more large trout (830).	Compared to Alternative A, highest catch rate; 22% fewer large trout (600).	Compared to Alternative A, second highest catch rates; 9% fewer large trout (700)..

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Glen Canyon—Fishing (Cont.)							
Navigability/ safety	No change from current conditions; intermediate number of days when flows below 8,000 cfs could affect navigability; minimal safety concerns from up-ramp rates.	Lowest navigability due to occasional flows below 8,000 cfs; slightly increased wading risk during tests of hydropower improvement flows.	Somewhat higher navigability than Alternative A; minimal safety concerns from up-ramp rates.	Same as Alternative A; minimal safety concerns from up-ramp rates.	Somewhat lower navigability than Alternative A; minimal safety concerns from up-ramp rates.	Somewhat higher navigability than Alternative A; minimal safety concerns, steady flows.	Highest navigability, with few if any flows below 8,000 cfs; minimal safety concerns, steady flows.
Glen Canyon—Day Rafting/Recreation							
Lost rafting visitor opportunities	No change from current conditions; estimated loss of 49 visitors/year out of a total of 50,000 due to HFEs (0.1%).	71 out of 50,000 fewer visitors/year due to HFEs.	315 out of 50,000 fewer visitors/year due to HFEs.	348 out of 50,000 fewer visitors/year due to HFEs.	177 out of 50,000 fewer visitors/year due to HFEs.	919 out of 50,000 fewer visitors/year because of large number of HFEs in peak rafting season.	51 out of 50,000 fewer visitors/year due to HFEs.
Camping and recreation facilities on old sediment terraces	No change from current conditions; lowest potential adverse impact on terraces; estimated 5.5 HFEs and no TMFs over the LTEMP period.	Intermediate potential impact on terraces; estimated 7.2 HFEs, 3 TMFs, and 4 years with hydropower improvement flows.	Intermediate potential impact on terraces; estimated 21.3 HFEs and 6 TMFs.	Intermediate potential impact on terraces; estimated 21.1 HFEs and 8 TMFs.	Intermediate potential impact on terraces; estimated 17.1 HFEs and 3 TMFs.	Highest potential impact on terraces; estimated 38.1 HFEs, but no TMFs.	Intermediate potential impact on terraces; estimated 24.5 HFEs and 11 TMFs.

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Grand Canyon—Whitewater Boating							
Campsite area	No change from current conditions; lowest improvement of campsite area; would continue long-term decline since there are no HFEs after 2020; camping area index (CAI) = 0.14 out of 1.	Compared to Alternative A, effects of 2 more HFEs offset by higher fluctuations; overall campsite loss is expected to continue, CAI = 0.15, an increase of 5% over Alternative A.	Comared to Alternative A, more HFEs and moderate fluctuations would result in a potential increase in camping area (CAI = 0.38, an increase of 170%).	Comared to Alternative A, more HFEs and comparable fluctuations would result in a potential increase in camping area (CAI = 0.36, an increase of 158%).	Comared to Alternative A, more HFEs and higher fluctuations would result in a potential increase in camping area (CAI = 0.30, an increase of 118%).	Compared to Alternative A, most HFEs, no daily fluctuations, and high sustained spring flowswould result in a potential increase in camping area (CAI = 0.41, an increase of 191%).	Comared to Alternative A, more HFEs, even monthly volumes, and no daily fluctuations would result in the highest potential increase in camping area (CAI = 0.45, an increase of 224%).
River flow level and fluctuations as indicated by the navigation index (NI) and the fluctuation index (FI)	No change from current conditions; intermediate NI (0.50 out of 1) and intermediate FI (0.79 out of 1) indicate good river conditions for whitewater boating most of the time.	Compared to Alternative A, 22% decrease in NI and 47% decrease in FI (lowest of alternatives) indicate decrease in boating conditions.	Compared to Alternative A, 50% increase in NI and 18% increase in FI indicate improvement in boating conditions.	Compared to Alternative A, 10% decrease in NI and 6% decrease in FI indicate decrease in boating conditions.	Compared to Alternative A, 26% decrease in NI (lowest of alternatives) and 28% decrease in FI indicate decrease in boating conditions.	Compared to Alternative A, 42% increase in NI and 27% increase in FI (highest of alternatives) indicate improvement in boating conditions.	Compared to Alternative A, 92% increase in NI (highest of alternatives) and 24% increase in FI indicate improvement in boating conditions.

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Lakes Powell and Mead—Recreation Access Issues Based on Reservoir Elevation							
Lake Powell (percent of seasons in which reservoir elevation drops below 3,580 ft)[b]	No change from current conditions; elevation drops below 3,580 ft in 21.8% of the seasons in the 20-year LTEMP period (percent of seasons with low reservoir elevations occurring in at least 1 month)	Compared to Alternative A, 2.6% increase in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, negligible increase (0.4%) in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 5.1% increase in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 5.1% increase in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 4.7% increase the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 4.7% increase the percent of seasons elevation drops below 3,580 ft.
Lake Mead (percent of seasons in which reservoir elevation drops below 1,050 ft)[c]	No change from current conditions; elevation drops below 1,050 ft in 25.5% of the seasons in the 20-year LTEMP period (percent of seasons with low reservoir elevations occurring in at least 1 month)	Compared to Alternative A, 10.6% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, negligible (0.3%) decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 2.5% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 1.2% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 2.5% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 1.9% decrease in the percent of seasons during which elevation drops below 1,050 ft.

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal Recreation Program							
Impacts on Tribal recreation operations in the Western Grand Canyon	No change from current sediment conditions; docks may be affected by HFEs until 2020 (average 5.5 over 20-year LTEMP period); lowest impact alternative.	Compared to Alternative A, approximately 2% increase in suspended sediment at RM 260; slightly greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 7.2 over 20-year LTEMP period).	Compared to Alternative A, approximately 3% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 21.3 over 20-year LTEMP period).	Compared to Alternative A, approximately 2% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 21.1 over 20-year LTEMP period).	Compared to Alternative A, approximately 3% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 17.1 over 20-year LTEMP period).	Compared to Alternative A, approximately 6% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 38.1 over 20-year LTEMP period); highest impact alternative.	Compared to Alternative A, approximately 2% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 24.5 over 20-year LTEMP period).
Park Facilities							
Impacts on park facilities at Pearce Ferry	No change from current conditions; facilities may be affected by HFEs; lowest impact alternative.	Slightly greater impacts than Alternative A due to slightly more frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.	Greatest impact alternative due to most frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.

[a] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs could reduce Alternative D’s impacts on Hualapai docks in the Western Grand Canyon.

[b] Percent of seasons with at least 1 month with Lake Powell elevations equal to or below 3,580 ft AMSL, the level below which boat ramp access is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. Seasons were defined as summer (May, June, July, August), winter (November, December, January, February), and spring/fall (March, April, September, October). See Appendix J.

[c] Percent of seasons with at least 1 month with Lake Mead elevations equal to or below 1,050 ft AMSL, the level below which marinas and boat ramp function is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. Seasons were defined as summer (May, June, July, August), winter (November, December, January, February), and spring/fall (March, April, September, October). See Appendix J.

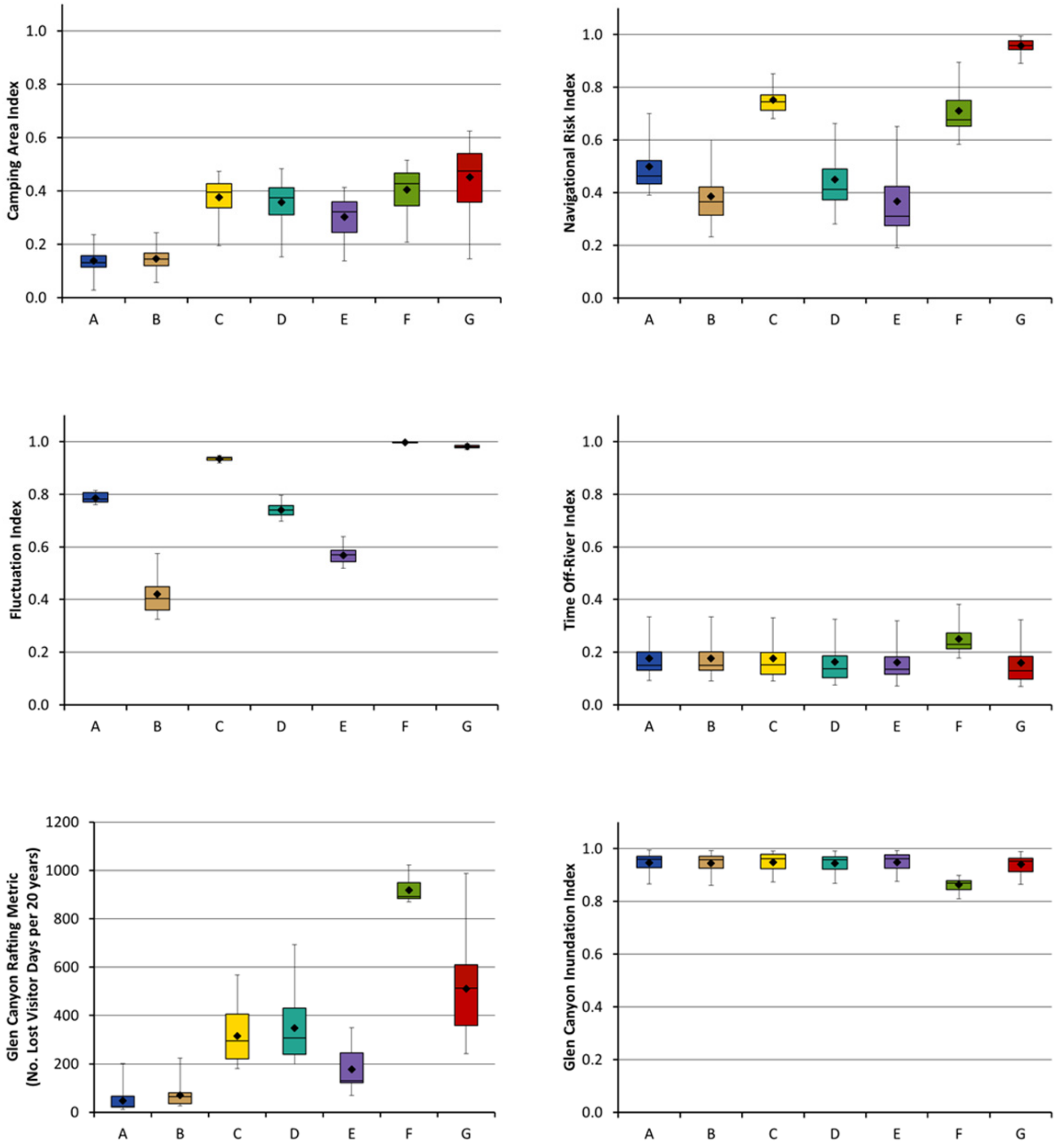

FIGURE 4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Steady flow Alternative F and Alternative G provide daily flows with no fluctuations; Alternative G might be considered better for anglers because flows would be at preferred levels throughout the year, whereas Alternative F has higher-than-preferred flows during some of the most popular fishing months, April through June. The highest fluctuations of fluctuating flow Alternatives C, A, D, E, and B (listed in order from lowest to highest within-day fluctuations) may not occur during peak fishing months. Furthermore, because the daily fluctuations analyzed in Bishop et al. (1987) were greater with respect to angling than those under the proposed alternatives, little difference is expected in effects on angling between alternatives due to fluctuations. Stewart et al. (2000) found that current fluctuations under MLFF were not identified by anglers as an issue. The effects of flow and fluctuation levels on angler satisfaction under the alternatives are quantified in economic terms in Section 4.14.2.1, which indicates that Alternative A would have the highest angler use value by a small margin over all alternatives; Alternative F would have the lowest due to high flows in peak fishing months.

The Glen Canyon Inundation metric was developed to identify the percentage of time river flows were above certain elevations that affect boating, fishing, and shoreline access. The metric is a measure of the suitability of flows between 3,000 and 31,500 cfs. Most alternatives perform similarly with regard to this metric, with Alternative F having a slightly lower metric value as illustrated in Figure 4.10-1. However, because all of the alternatives perform so consistently on this metric, it will not be discussed further.

Fishing would be disrupted during HFEs under all alternatives. The average number of HFEs over the 20-year LTEMP period would vary among alternatives, and would range from 5.5 under Alternative A to 38.1 under Alternative F; Alternative D would have an average of 21.1 HFEs[24] over the 20-year period. The maximum number of days that HFEs would disrupt fishing in any year would range from 4 under Alternative B to 18 under Alternative G; Alternative G is highest because it includes the potential for extended-duration HFEs that are up to 14 days long (Alternative D would have a maximum of 10 HFE days within a calendar year). Extended-duration HFEs are expected to be triggered relatively infrequently and would be limited to no more than four under Alternative D (Section 4.3.3).

Effects of Fish Size and Catch Rates

Anglers in the Glen Canyon reach are almost evenly split in their preference for catching either large fish or for catching more fish (Anderson, M. 2012). Analysis described in more detail in Section 4.5.2.2 concludes there will likely be differences among the alternatives both in the percentages of larger fish (individuals exceeding 16 in. in length) in the population and in the angler catch rate. Among the alternatives, the estimated number of large trout was generally greatest under Alternative B and lowest under Alternatives F and G. Alternatives E, D, A, and C in descending order are expected to produce intermediate numbers of large trout. The modeled

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[24] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs is not expected to result in a change in Alternative D’s impacts on recreation.

angler catch rates are greatest under Alternatives F and G because of their steadier flow regimes, and lowest under Alternative B, with the greatest fluctuations. It is anticipated that recreational angling use in the Glen Canyon Reach would be similar to current conditions under all alternatives and that angler satisfaction would likely remain high, but satisfaction for some alternatives would be based on the size of fish, while that of others would be based on the number of fish.

Navigability and Wading Safety in the Glen Canyon Reach

The ability for boats to navigate freely within the Glen Canyon reach was an issue when low flows of 1,000–3,000 cfs occurred prior to 1996. All alternatives now include a minimum 5,000 cfs flow between 7 PM and 7 AM, and 8,000 cfs from 7 AM to 7 PM (with the exception of Alternative F, which has flows near or somewhat below 8,000 cfs all day during the summer, fall, and winter). The Navigation Index (Figure 4.10-1) is based on the amount of time flows are above 8,000 cfs. Alternatives B and E have lower Navigation Index values than Alternative A due to more frequent low flows. Alternatives C, F, and G are higher than Alternative A, and Alternative D is about the same as Alternative A.

Wading anglers are always at risk from swift water and from rapidly rising water levels, and anglers are urged to exercise caution. Specifically, rapidly increasing flow is a safety concern with respect to the ability of wading anglers to move toward shore. At least three drownings in 12 years preceding the 1995 EIS possibly were related to river stage or stage change (Reclamation 1995). Implementation of the MLFF protocol limiting up-ramp rates to 4,000 cfs/hr for all fluctuating-flow alternatives has reduced the potential safety concerns for wading anglers. An up-ramp rate of 5,000 cfs/hr proposed under Alternative B during tests of hydropower improvement flows could result in an adverse impact on safety of anglers due to rapidly rising water levels. With respect to HFEs, Reclamation and NPS would coordinate to ensure that safety measures are implemented during an HFE, including restricting access immediately below Glen Canyon Dam, and providing public notice about the timing of an HFE. Each of the affected NPS units—GCNRA, GCNP, and Lake Mead National Recreation Area (LMNRA)—has clearly designated responsible parties, staffing needs, and actions that are required to occur prior to and during an HFE.

4.10.2.2 Glen Canyon Day Rafting

The 15-mi Glen Canyon reach hosts a large number of day rafters who use the pontoon-raft concession that departs from near Glen Canyon Dam and travels to Lees Ferry (Section 3.11.1.2). Bishop et al. (1987) established that day rafting participants express no preferences regarding either river flows or fluctuations. As a result, impacts on rafting use are related only to the occurrence of HFEs, which result in lost visitor recreation opportunities and lost revenue for the rafting concessioner. The variables influencing the level of impact are the number of HFEs and the time of year in which they occur. Spring HFEs have a greater impact than fall HFEs because visitor use is higher in the spring months. HFEs are scheduled only in

October, November, March, and April, with the exception of proactive spring HFEs (under Alternatives C, D, and G), which can occur in April, May, or June.

Because of the high number of HFEs, Alternative F would have by far the greatest adverse impact on day-use rafting with an anticipated mean annual loss of about 919 visitor opportunities over the LTEMP period out of a typical annual total of 50,000 such trips expected over the LTEMP period. Alternatives G, D, C, and E would have the next largest adverse impacts with 512, 348, 315, and 177 mean annual lost visitor use opportunities, respectively. Alternatives A and B would be similar in their impact and would result in 49 and 71 mean annual lost visitor use opportunities, respectively (Figure 4.10-1).

4.10.2.3 Glen Canyon Recreational Facilities

Glen Canyon contains both high-elevation sediment terraces, which are remnants of larger terraces that existed prior to construction of Glen Canyon Dam, and lower elevation terraces, which are still affected by dam operations. Glen Canyon has six designated campsites with fire pits and bathrooms along its 15-mi stretch. These recreational facilities are generally located above the high-water level of normal dam operations; however, HFEs are the principal flow actions that could affect these campsites through erosion of terraces combined with an absence of sediment sources in the Glen Canyon reach for possible deposition and rebuilding of terraces. Alternative F would have the largest adverse impact on these facilities from the projected number of HFEs and annual high releases (Table 4.3-1), followed by Alternatives G, C, D, E, B and A, in decreasing order. In addition, higher fluctuation levels, including during tests of hydropower improvement flows under Alternative B, could lead to increased campsite erosion relative to the other alternatives.

4.10.2.4 Whitewater Boating

The availability, size, and quality of campsites in the Grand Canyon is an important resource for whitewater boaters. As discussed in Section 3.11-2, total campsite area has undergone a long-term downward trend due to sandbar erosion and vegetation growth, having decreased by 56% from 1998 to 2006 (Kaplinski et al. 2010). Generally, alternatives with more sediment-triggered HFEs are expected to result in greater campsite area, although flow and fluctuation levels as well as vegetation control will affect the maintenance of campsite area. Alternatives G and F show the highest potential to create and maintain campsite area based on Camping Area Index values (Figure 4.10-1). These are followed by Alternatives C, D, and E which have index values more than two times greater than those of Alternatives A and B.

River flow levels and fluctuations are important for whitewater boaters (Bishop et al. 1987; Hall and Shelby 2000; Stewart et al. 2000; Roberts and Bieri 2001). The minimum daily flow levels of 5,000 cfs from 7 PM to 7 AM and 8,000 cfs from 7 AM to 7 PM provided by most alternatives are considered only minimally adequate for Grand Canyon boating. Transit times of morning flow increases to 8,000 cfs from 5,000 cfs overnight at the dam to downstream locations may delay the arrival of 8,000 cfs or higher desired at more challenging rapids. Such concerns would arise only in low-volume months, however, when minimum flow limits would be applied. Flows on most days under the fluctuating flow alternatives would exceed these limits. Steady flow Alternatives F and G could feature daily flows of 5,000 cfs for extended periods of time; however, only four occurrences of 5,000 cfs flows for a period of a month or more appeared in LTEMP 20-year hydrology simulations for Alternative F, and there were none for Alternative G. Extended low flows of 5,000 cfs would adversely affect navigability and trip management in GCNP because of a greater risk of boating incidents. Conversely, the normal steady flows of Alternatives F and G would offer benefits to river trip planning over the alternatives with fluctuating flows because river travel time and off-river time is more predictable. Commercial and private whitewater trip leaders reported (Bishop et. al. 1987) a preference for steady flows in the 20,000–26,000 cfs range. Alternative F approaches these levels in April through June, and thus would have higher perceived value to rafters than would Alternative G, which limits flows to near 12,000 cfs or less year round in 8.23-maf years.

The Navigation Index and the Fluctuation Index both address aspects of the impact of fluctuations on whitewater boating (Figure 4.10-1). Both indices are designed to produce values that increase in the direction of improved boating conditions. Thus, a higher Navigation Index value indicates that an alternative presents relatively lower navigation risks due to low flows (below 8,000 cfs), while higher Fluctuation Index values indicate that an alternative will have fluctuations more often within a preferred range for whitewater boating (Bishop et al. 1987). Alternatives G, F, and C have the highest values for both indices (indicating the best conditions), while Alternatives B and E had the lowest index values (indicating the worst conditions). Alternatives A and D have intermediate values for these two indices.

The Time Off-River Index values indicate there would not be much difference in time available for off-river activities between the alternatives, likely due to similar mean annual flows of between 10,000 and 15,000 cfs. Because the index does not provide a meaningful distinction among the alternatives, it will only be referenced in special circumstances in Section 4.10.3.

4.10.2.5 Reservoir Activities and Facilities

Recreation on Lakes Powell and Mead can be affected by water levels dropping below the level at which ramps and marinas can function. In the case of Lake Powell, the Castle Rock cut is also a critical feature. Although the lowest boat ramp elevations on Lake Powell are not all the same, 3,580 ft AMSL is representative of the level below which major access issues occur. The frequency at which reservoir elevations would be above 3,580 ft AMSL at the end of the month seasonally has been analyzed to determine whether there is any significant difference among the alternatives. The same has been done for Lake Mead using an elevation of 1,050 ft AMSL, the level to which the NPS has committed in order to keep marinas and launch ramps functional.

Simulations were performed of end of the month reservoir elevations by season (summer [May, June, July and August], winter [November, December, January, and February], or spring/fall [March, April, September, and October]) for the 20-year CRSS simulations using

21 hydrology traces for both reservoirs. For Lake Powell, with respect to the 3,580 ft AMSL reference level for boat access, approximately 22% of all simulated seasons showed at least one month with end of the month elevations at or below this level for all alternatives. There was very little difference among the alternatives; all alternative means fall between 21.75% for Alternative A and 22.86% for Alternative E. Such differences by alternative are due to small changes in elevation when reservoir elevation is near the 3,580-ft reference level.

The results for Lake Mead simulations were similar to those for Lake Powell, with a slightly greater range of results. Alternative B, with 22.78%, had the lowest percentage of seasons with at least 1 month at or below the reference elevation, and Alternative A, with 25.48%, had the highest. Differences by alternative are due to small changes in elevation when reservoir elevation is near the 1,050-ft reference level.

As discussed in Section 4.2.2.1, the elevations of Lake Powell and Lake Mead are more affected by annual variation in inflow than by alternative. The dominating effect of hydrology was also observed in the analysis of reservoir elevations with respect to reservoir access, with relatively small effects attributable to differences in alternatives. With respect to ongoing drought conditions affecting operations at LMNRA, as noted in Section 3.10.3.1, an October 2005 NPS General Management Plan Amendment for Low Water Conditions and a Finding of No Significant Impact (NPS 2005b) identified the current strategy for low-water operations. This amendment articulated the intent to maintain boat-launch capacities established in the original General Management Plan of 1986 and a subsequent amendment in 2003, by either extending or relocating existing launch ramps and marinas to be functional down to an elevation of 1,050 ft AMSL. This amendment reflects the current management direction for low-water operations, and it assumes that NPS and concessionaires will continue to modify launching and marina facilities as necessary and possible, given time and budget to continue providing visitor services.

4.10.2.6 Tribal Recreation Operations

The Hualapai Tribe operates recreational facilities in the Western Grand Canyon, and their facilities and activities could be adversely affected by operation of Glen Cayon Dam. The Hualapai have expressed concern over dam operations they believe are increasing the amount of sediment collecting in the channel in their operational area below Diamond Creek. Their primary operations are centered in and around the Quartermaster area (RM 260). They have reported adverse impacts on their commercial operations from river sediment, including effects on equipment, access to their docks, and navigation in the river.

They are also concerned over the steep and unstable slopes previously inundated by Lake Mead that are now exposed due to reservoir levels retreating from the previous high-water line. The issues associated with the steep and unstable shorelines in the Lake Mead delta are related to the declining reservoir level, and will not be resolved until the level of Lake Mead either regains its previous high levels or until the banks naturally stabilize under new, lower reservoir levels.

The Hualapai are also concerned with the effect of different flows on their boat docks. The number and duration of HFEs under LTEMP alternatives could affect boat docks and other facilities operated by the Hualapai Tribe. LTEMP alternatives differ in the frequency and type of HFEs that would occur over the 20-year LTEMP period (Table 4.10-1; Sections 4.3.2 and 4.3.3). Alternative A would have the fewest (average of 5.5 HFEs over the LTEMP period, with HFEs not being conducted after 2020); Alternative F would have the most (average of 38.1 HFEs over the entire LTEMP period).

Reclamation engineers evaluated the Haulapai dock structures in 2012 to consider, among other things, the effect of high flows and related sediment on the dock structures (Walkoviak 2012). The conclusion of this assessment was that "the docks as designed and built are currently at risk of failure under essentially any Glen Canyon Dam operating regime, including normal operations" and the "docks are already at risk of failure regardless of future HFE implementation." Based on this assessment, Reclamation concluded that "there are no appropriate actions necessary regarding these [dock] structures in advance or following a HFE." Reclamation recommended that the operators undertake "a thorough structural, geotechnical, and hydraulic engineering review, and consider rebuilding the structures to standards that would allow certification by a licensed civil engineer."

Since the 2012 assessment, Reclamation has not been notified of any modifications to the dock structures to address the structural issues identified. Accordingly, concerning the potential effects of HFE-related sediment discussed above, Reclamation's position continues to be that there is "no appropriate mitigation for HFEs for the docks as currently built." If modifications are made, Reclamaton will consult with the Haulapai Tribe to discuss next steps.

Regarding the potential for differences among alternatives in their impacts on sediment issues near Hualapai facilities at RM 260, it is expected that dam operations, HFEs, equalization flows, and other flow events will continue to deliver sediment to the Western Grand Canyon and Lake Mead. Nearly all sediment that enters the Grand Canyon below Lake Powell will eventually move downstream to the area of concern. Higher flows, in general, do transport more sediment, and sediment transport will continue in the free-flowing portions of the river below Diamond Creek.

Transport of sand downstream from sources in Marble Canyon (RM 0–RM 61) under various LTEMP alternatives is discussed in Sections 4.3.2 and 4.3.3. The least amount of sand that would be transported would be under Alternative A, primarily because, under this alternative, the HFE protocol would expire in 2020; HFEs are the major source of sand transport under the alternatives. Sand transport would be second lowest under Alternative D and greatest under Alternatives F and G.

One metric that helps explain the potential for differences in sediment that would be relevant to Hualapai recreational operations is the amount of sediment leaving Marble Canyon at RM 61. Table 4.10-2 presents those values for each alternative, as determined from sediment

TABLE 4.10-2 Amount of Sediment Transported Out of Marble Canyon under the LTEMP Alternatives over the 20-Year LTEMP Period

	Alternative						
Indicators	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Sand leaving Marble Canyon (ktons)	17,900	18,800	19,200	18,600	19,100	20,500	19,000
Sand leaving Marble Canyon (% change from Alternative A)	0	5	7	4	7	15	6
% change in suspended sand at RM 225 relative to Alternative A	0	2	3	2	3	6	2

modeling. However, many factors must be considered when trying to assess how these values for RM 61 would relate to sediment settling out at Hualapai facilities near RM 260:

- Based on the results of quantitative modeling performed for the LTEMP, LTEMP alternatives would differ in the amount of suspended sediment transported out of Marble Canyon.

- The sediment model does not estimate transport past the end of Marble Canyon (RM 61). Data at the USGS gage (number 09404200) above Diamond Creek in GCNP (RM 225) was used to estimate values at RM 260.

- Approximately 50% of the sand that is in suspension at RM 225 (and presumably in suspension at the Hualapai facilities at RM 260) is from sources other than Marble Canyon; therefore more than half of the sand in suspension at RM 260 is independent of dam operations and comes from the Little Colorado River and other tributaries downstream of Marble Canyon.

- Some portion of the suspended sediment being transported may settle out in the channel at RM 260; that portion is dependent on a number of factors, including the elevation of Lake Mead and local hydraulic conditions (e.g., velocity and depth). Unless there is a significant geomorphic change near Quartermaster Canyon—such as a change in slope, width, or Lake Mead elevation— suspended sand would likely continue to travel downstream.

- Variability in sand transport out of Marble Canyon based on potential future hydrology is much larger than any variation in sand transport due to LTEMP alternatives considered in this EIS.

The average amount of suspended sand passing RM 225 is approximately 44,000 ktons over 20 years. The increase in suspended sand at RM 225 relative to Alternative A is approximately 6% for Alternative F, approximately 2% for Alternative D, and under 3% for all other alternatives (Table 4.10-2). This difference is significantly less than the differences under potential future hydrologic conditions. The location where this suspended sand deposits downstream of RM 225 will be a function of Lake Mead elevation and local hydraulic conditions. However, the amount will not be more that what is in suspension, so the sand deposition at RM 260 will be much less than the 2 to 6% increase in suspended sand expected under the LTEMP action alternatives.

4.10.2.7 Pearce Ferry

Park facilities at Pearce Ferry, managed by LMNRA, have been damaged in the past by HFEs and may be affected by HFEs in the future. Effects would vary among alternatives, and those with more frequent HFEs, particularly spring HFEs, could have greater impact. In the months following HFEs, there would be temporary impacts on both park operations and visitor access when there is damage, until the takeout ramp is repaired. Damage in April–June (following a spring HFE) would have greater impact on visitors than damage in November–January (following a fall HFE).

4.10.2.8 Park Operations and Management

As discussed in Section 3.10.4, potential effects on NPS staffing levels are related to recreation and resource concerns. For this analysis, staff levels were generally calculated as full-time equivalents, based upon known amounts of time currently dedicated to operational functions. To estimate the changes to staff levels that might be different among alternatives, an assumed relationship to a quantitative metric from modeling was used. For instance, if vegetation modeling indicated a 5% increase in nonnative invasive plants, it was assumed that there would be a 5% increase in the need for vegetation treatment work. Staff time for monitoring and maintenance of camping beaches and trails was estimated using the modeled Camping Area Index. Staff time related to special flows, such as HFEs or TMFs, was estimated based on the tracking of GCNRA and GCNP staff time for notification and coordination related to HFEs from 2011 to 2015. Flow patterns were looked at in terms of safety, and boating hazards and staff time for ranger patrols were analyzed, though this was looked at as trend information rather than quantitative contributions to the total as staff time for safety issues can vary greatly from year to year.

Another consideration that was evaluated was impacts on park facilities at Pearce Ferry, managed by LMNRA, as these facilities have been damaged in the past by HFEs and are likely to be damaged by HFEs in the future. Effects would vary between alternatives, as those with more frequent HFEs, particularly spring HFEs, may have more effects than those with fewer HFEs. There would be temporary impacts in the months following HFEs to both park operations and visitor access when there is damage, until the takeout ramp is repaired. Damage in April–

June (following a spring HFE) would have more impact on visitors than damage in November–January (following a fall HFE).

Based on the analysis conducted, the maximum difference between action alternatives (B through G) and Alternative A was a 1.8 full-time equivalent decrease (Alternative D), and the maximum was an increase of 0.1 full-time equivalent (Alternative B). However, factors such as safety response and repairs at Pearce Ferry, which were considered but were not possible to quantify, did not vary in the same direction as the quantified effects. Therefore, the differences among alternatives may be less than indicated by the quantified effects. Based on this analysis, it was determined that the variation among alternatives for park staffing for recreation and resource concerns would be negligible.

4.10.3 Alternative-Specific Impacts

The following section provides descriptions of impacts that are expected to occur under each of the LTEMP alternatives.

4.10.3.1 Alternative A (No Action Alternative)

Under Alternative A, trout abundance, size, and catch rates are expected to vary within the ranges that have been observed under MLFF operations over the past 20 years. About 770 large trout (a number intermediate among the alternatives; large trout are defined as individuals exceeding 16 in. in length) would be expected under Alternative A, as well as intermediate levels of angler catch rates (Section 4.5.3.1). Fishing would be disrupted during HFEs, but the number of HFEs under Alternative A is the lowest of all alternatives (5.5) and HFEs would not be conducted after 2020. The maximum number of days that HFEs would disrupt fishing in any year would be 8 if a spring and fall HFE were conducted in the same calendar year. Therefore, under Alternative A overall angler satisfaction is anticipated to remain the same as at present, with a consistent trend in the fishery toward more, but smaller, fish. Alternative A is expected to result in the highest angler satisfaction of all alternatives, by a small margin (Section 4.14.2.1).

The current MLFF maximum up-ramp rate of 4,000 cfs/hour under this alternative has been adopted for all LTEMP alternatives and it is not anticipated that this ramp rate would create angler safety issues. The down-ramp rate of 1,500 cfs is the same as the current rate and also does not create issues for anglers.

Because this alternative only allows for HFEs until 2020 and has the fewest total number of HFEs, Alternative A scores the best among alternatives in the Glen Canyon Rafting Metric, with a projected mean annual loss of only 49 visitor rafting trips (Figure 4.10-1), compared to a total mean annual visitor use of 50,000 visitors. This is a 0.01% reduction. In addition, the lower number of HFEs would result in the lowest anticipated impact on the sediment terraces and the recreational resources they support.

With respect to whitewater boating, about 80% of the time daily fluctuations would remain in a range preferred by whitewater boaters (FI = 0.79) (Figure 4.10-1). Navigational boating risks due to flows below 8,000 cfs under Alternative A, as reflected in the navigation index, would be about in the middle of the range for all alternatives (NI = 0.50) (Figure 4.10-1). Having the lowest mean number of HFEs over the LTEMP period, Alternative A has among the lowest potential for increasing campsite area of all alternatives, with a camping area index value of 0.14 (Figure 4.10-1). Based on observed effects under the current MLFF operating regime, this alternative is expected to lead to a continued loss of campsite area due to erosion and increased campsite crowding.

There would be no change in current sediment conditions that could affect Hualapai recreation operations in the Western Grand Canyon, but these facilities could be affected by HFEs until 2020 (average 5.5 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative A, including mechanical removal of trout in the Little Colorado River reach and testing TMFs. Mechanical trout removal activities are intensive activities that can last many days and over a period of several months (Reclamation 2011a). Mechanical trout removal activities would have a short-term impact to visitor experience from motorized use. Based on modeling of trout numbers, there is a low probability that this activity will occur under Alternative A during the LTEMP period.

In summary, there would be little change from current conditions under Alternative A. Alternative A would have the fewest HFEs (ending in 2020) that could affect fishing and boating, and moderate flow fluctuations. Anglers would expect to see intermediate numbers of large trout and intermediate catch rates. Few navigability concerns from low flows would occur. Concerns for angler safety from high up-ramp rates would be low. Alternative A would have the fewest lost day rafting trips in Glen Canyon resulting from HFEs. Ongoing loss of camping area would continue, leading to increased crowding. There would be very little interference with recreation from testing and implementing experimental elements under the alternative.

4.10.3.2 Alternative B

Of all the alternatives, Alternative B has the lowest estimated number of rainbow trout and trout emigrants in the trout fishery below Glen Canyon Dam, but it has the greatest estimated number of large rainbow trout (>16 in.), about 870 fish. Hydropower improvement flows, which may occur in 4 out of 20 years, would be expected to result in even lower trout abundance and emigration and an increase in the numbers of large trout (Section 4.5.3.2). Angler catch rates would be the lowest of all alternatives because of the relatively low number of trout under this alternative. Fishing would be disrupted during HFEs, but the number of HFEs under Alternative B (7.2) is comparable to the number under Alternative A (5.5). The maximum number of days HFEs would disrupt fishing in any year would be 4, because, under Alternative B, no more than one HFE would be conducted every other year. Alternative B is expected to have angler satisfaction related to flow levels and fluctuations similar to that under Alternative A. High daily fluctuations (up to 66% higher), down-ramp rates as high as 4,000 cfs/hour (2.7 times higher than under Alternative A), and more frequent flows below 8,000 cfs result in relatively low navigability (Figure 4.10-1).

Alternative B is expected to have slightly more HFEs than Alternative A, and would result in an anticipated mean loss of 71 annual Glen Canyon day-rafting opportunities (Figure 4.10-1). Under Alternative B, there is a slightly increased likelihood of additional impacts on sediment terraces in the Glen Canyon reach that support recreation facilities and campsites.

There would be a slight increase (3%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, but the total number of HFEs would be comparable to the number under Alternative A (average 7.2 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

Whitewater boating would be affected by high daily fluctuations under Alternative B; daily fluctuations would remain in a range preferred by whitewater boaters only about 42% of the time (FI = 0.42), the lowest of all alternatives. As reflected in a NI value of 0.39, navigational boating risks due to flows below 8,000 cfs under Alternative B would be the second highest. In addition, the down-ramp rate is 2 to 2.6 times higher than under Alternative A, which could lead to boats being stranded in both GCNRA and GCNP. Alternative B is expected to result in slightly more camping area than Alternative A (CAI = 0.15) (Figure 4.10-1) due to a higher number of HFEs, but there would be a continued declining trend in campsite area due to high flow fluctuations. Total number of campsites and campsite area would continue to decrease under Alternative B, potentially increasing competition and crowding at campsites.

In addition to HFEs, Alternative B includes experimental testing of mechanical removal of trout in the Little Colorado River reach, TMFs, and hydropower improvement flows in 4 years during the LTEMP period when annual volume is ≤8.23 maf (Section 2.2.2).

The impacts of mechanical trout removal activities would be similar to those described under Alternative A; however, based on modeling of trout numbers there is a low probability that this activity will be triggered under Alternative B during the LTEMP period.

TMFs are expected to be triggered relatively infrequently under this alternative (mean of three TMFs triggered over the 20-year LTEMP period); therefore the overall impact of TMFs on recreation is expected to be minimal. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are intended to decrease trout abundance in the fishery in the Glen Canyon reach, which could result in a reduced angler catch rate but could also increase the number of larger fish.

Tests of hydropower improvement flows in 4 years when annual volume is ≤8.23 maf would more closely resemble the operations at Glen Canyon Dam prior to the early 1990s, and would produce daily fluctuations up 20,000 cfs (5,000 cfs nighttime to 25,000 cfs daytime). The daily minimum flow would be 5,000 cfs and the up- and down-ramp rates would each be 5,000 cfs/hr. High ramp rates, when combined with the overall level of fluctuations under Alternative B, would create additional difficulties in navigating rapids and managing boats tied to shore. In the 1995 EIS (Reclamation 1995), rapidly increasing flow was identified as a safety concern for wading fishermen with respect to their ability to move toward shore. This pattern of river fluctuations and high daytime flows would also adversely affect fishing and usable campsite area.

In summary, Alternative B would have the second fewest HFEs and the greatest flow fluctuations; the former would result in relatively few days that would disrupt angling and boating from river closings, similar to Alternative A, and the latter would result in reduced whitewater boater satisfaction due to high daily fluctuations compared to Alternative A. The number of large trout would be highest of all alternatives, but catch rates lowest. Navigability and boat stranding concerns would be the greatest of all alternatives due to high fluctuations and high down-ramp rates, but relatively low overall. There would be few lost day rafting trips in Glen Canyon due to HFEs, similar in number to Alternative A. Camping area is expected to continue to decrease due to erosion, similar to Alternative A. Interference with recreation from testing and implementing experimental elements would be low and similar to that under Alternative A, with the exception of hydropower improvement flows, which would produce greater impacts than under Alternative A.

4.10.3.3 Alternative C

Under Alternative C, about 750 large trout are predicted to be present below Glen Canyon Dam, similar to the number under Alternative A (770); angler catch rates would be similar to those under Alternatives A, D, and E, more than under Alternative B and less than under Alternatives F and G (Section 4.5.3.3). Fishing would be disrupted during HFEs, and the number of HFEs under Alternative C (21.3) is much higher than the number under Alternative A (5.5). The maximum number of days HFEs could disrupt fishing in any year would be 10 under Alternative C (if a spring HFE and extended-duration fall HFE were conducted in the same calendar year). Angler satisfaction related to flow levels and fluctuations under this alternative is expected to be similar to that of Alternative A. The down-ramp rate is 1.7 times that under Alternative A, but it is not expected to create an issue for anglers.

The more frequent HFEs under this alternative (including proactive spring HFEs and extended-duration fall HFEs) would result in an estimated 315 lost day-rafting visitor opportunities in Glen Canyon (Figure 4.10-1) as compared to a loss of 49 such opportunities under Alternative A. In addition, under Alternative C, the larger mean number of HFEs is expected to result in erosion of sediment terraces from wetting and undercutting in the Glen Canyon reach that support recreation facilities and campsites.

Daily fluctuations would remain in a range preferred by whitewater boaters most of the time (FI = 0.93). The low frequency of flows below 8,000 cfs results in good navigation (NI = 0.75), exceeded only by Alternative G. Because of the relatively high number of HFEs and moderate fluctuations under Alternative C, it has a higher probability of producing an increase in campsite area compared to Alternative A (Figure 4.10-1).

There would be a slight increase (3%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 21.3 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to HFEs, Alternative C includes experimental testing of mechanical removal of trout in the Little Colorado River reach, TMFs, and low summer flows. Mechanical trout removal activities would be triggered infrequently and could temporaily limit visitor access to portions of the river for several days over several months when they occur.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate, but could also result in an increased number of larger fish in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are expected to be triggered six times during the 20-year LTEMP period under Alternative C, compared to no TMFs under Alternative A (Table 4.9-2).

The impacts of testing low summer flows would vary depending on the level of flows and the number of years they are employed. Flows of 8,000 cfs would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, and potentially more difficult navigation.

In summary, Alternative C would have almost four times the number of HFEs that could affect fishing and boating, compared to Alternative A, but lower daily fluctuation levels. Angler satisfaction with flow rate and fluctuations would be similar to that under Alternative A, and so would the number of larger trout and trout catch rates. Few navigation concerns would exist, similar to Alternative A. However, the number of lost day rafting trips in Glen Canyon due to HFEs would be about six times the number under Alternative A, but this is still a small fraction of total rafting trips. Camping area is expected to increase somewhat due to the effects of HFEs, while continued reduction is expected under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.4 Alternative D (Preferred Alternative)

Under Alternative D, an estimated 810 large trout are predicted to be present in the trout fishery below Glen Canyon Dam, with angler catch rates similar to those under Alternatives A, C, and E; this would be more than under Alternative B, and less than under Alternatives F and G (Section 4.5.3.4). Fishing would be disrupted during HFEs, and the number of HFEs under

Alternative D (21.1)[25] is much higher than under Alternative A (5.5). The maximum number of days that HFEs could disrupt fishing in any year would be 10 under Alternative D (if an extended-duration fall HFE were conducted). Angler satisfaction related to flow levels and fluctuations under Alternative D is expected to be similar to that under Alternative A. The down-ramp rate is 1.7 times that under Alternative A, but it is not expected to create an issue for anglers.

The more frequent HFEs under this alternative (including proactive spring HFEs and extended-duration fall HFEs) would result in an estimated 348 lost day-rafting visitor opportunities in Glen Canyon (Figure 4.10-1) as compared to a loss of 49 such opportunities under Alternative A. In addition, more frequent HFEs under Alternative D compared to Alternative A are expected to result in relatively greater erosion of sediment terraces due to wetting and undercutting the Glen Canyon reach that supports recreation facilities and campsites.

Daily flow fluctuations (FI = 0.74) and daily minimum flows that may affect navigability (NI = 0.45) under Alternative D are lower those under Alternative A, and intermediate among all alternatives for both metrics. Because of the relatively high number of HFEs and moderate fluctuations, Alternative D is expected to increase campsite area (CAI = 0.36) more than Alternatives A, B, and E, and less than Alternatives C, F, and G (Figure 4.10-1).

There would be a slight increase (2%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 21.1 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to HFEs, Alternative D includes experimental testing of mechanical removal of trout in the Little Colorado River reach, TMFs, macroinvertebrate production flows, and low summer flows. Although there can be direct effects of these experiments on recreation, long-term indirect benefits for recreation may accrue from the adoption of successful treatments, including potentially improved aquatic food base that supports the trout fishery.

Mechanical trout removal activities, although triggered infrequently, might limit visitor access to portions of the river for several days over several months when they occur.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate; however, it could also result in an increased number of larger fish in the fishery in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are expected to be triggered in 8 years over the 20-year LTEMP period, compared to no TMFs under Alternative A (Table 4.9-2).

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[25] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs is could result in a decrease in Alternative D's impacts on Hualapai docks in the Western Grand Canyon.

Low summer flows would be tested only in the second 10 years of the 20-year LTEMP period. Flows of 8,000 cfs or less would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, potentially more difficult navigation, and potential loss of business by commercial rafters and fishing guides because of low flows. Testing macroinvertebrate production flows would feature steady flows on every weekend from May through August (34 days total). Under this experiment, the flow on weekends would be held to the minimum flow for that month. Effects on recreation would be similar to those for low summer flows.

In summary, Alternative D would have almost four times the number of HFEs that could disrupt fishing and boating and similar daily fluctuation levels, compared to Alternative A. Angler satisfaction with flow levels and fluctuations would be similar to that underAlternative A, as would the number of larger trout and trout catch rates. Few navigation concerns would exist, similar to Alternative A. However, the number of lost rafting trips due to HFEs would be about seven times that of Alternative A. Camping area is expected to increase somewhat due to the effects of HFEs, compared to an expected reduction under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.5 Alternative E

Alternative E is expected to result in an estimated number of rainbow trout and trout emigrants near the low end of alternatives and similar to Alternative A, with the second-highest expected number of large rainbow trout (about 830 fish) in the trout fishery below Glen Canyon Dam after Alternative B (Section 4.5.3.5). Angler catch rates similar to those under Alternative A would be expected. Fishing would be disrupted during HFEs, and the number of HFEs under Alternative E (17.1) is much higher than under Alternative A (5.5). The maximum number of days HFEs could disrupt fishing in any year would be 8 under Alternative E (if a spring HFE and fall HFE were conducted in the same calendar year). Angler satisfaction related to flow levels and fluctuations under Alternative E is expected to be similar to that under Alternative A. The down-ramp rate of this alternative is 1.7 times that of Alternative A, but it is not expected to create an issue for anglers.

The more frequent HFEs under this alternative would result in an estimated 177 lost day-rafting visitor opportunities in Glen Canyon (Figure 4.10-1), an increase of 146 over Alternative A. In addition, under Alternative E, the larger mean number of HFEs is expected to result in an increase in adverse impacts on sediment terraces in the Glen Canyon reach that supports recreation facilities and campsites, compared to Alternative A.

Daily fluctuations would be in the range preferred by whitewater boaters only about half of the time (FI = 0.57) and is lower than under all other alternatives except Alternative B, while flows would be below 8,000 cfs more frequently than all other alternatives (NI = 0.37), slightly more frequent that Alternative B. Because of the relatively high number of HFEs under Alternative E, this alternative is expected to increase campsite area (CAI = 0.30) more than Alternatives A and B, but somewhat less than Alternatives C, D, F and G.

There would be a slight increase (3%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 17.1 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative E, including mechanical removal of trout in the Little Colorado Reach, testing and implementing TMFs, and testing low summer flows in the second 10 years of the LTEMP period.

The impacts of mechanical removal of trout in the Little Colorado reach would be similar to those described under Alternative A. Overall, there is a low probability that this action would be triggered during the LTEMP period based on the expected number of trout in the Little Colorado River reach.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate; however, it could also result in an increased number of larger fish in the fishery in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are expected to be triggered in 3 years over the 20-year LTEMP period, compared to no TMFs under Alternative A (Table 4.9-2).

The impacts of testing low summer flows would be the same as discussed under Alternative C. When they are tested, summer flows of 8,000 cfs would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, potentially more difficult navigation, and potential loss of business by fishing guides due to angler perception of less-desirable fishing conditions.

In summary, Alternative E would have three times as many HFEs that could affect fishing and boating and similar daily fluctuations, compared to Alternative A. Angler satisfaction with flow levels and fluctuations would be similar to that under Alternative A. The number of large trout would be higher than under Alternative A, while catch rates would be similar to those under Alternative A. Few navigation concerns would exist, but slightly more than under Alternative A. The number of lost rafting trips due to HFEs would be 3 to 4 times that of Alternative A, but still a small fraction of total rafting trips. Camping area is expected to increase somewhat due to the effects of HFEs, compared to an expected reduction under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.6 Alternative F

The steady daily flows of Alternative F are expected to result in higher numbers of trout and increased angler catch rates, but the lowest number of large trout of all alternatives (600 fish) (Section 4.5.3.6). In addition, this alternative does not include any trout management actions (i.e., mechanical removal and TMFs). Angler satisfaction related to flow levels and fluctuations under Alternative F, however, is anticipated to be lowest of all alternatives due to high flows during peak fishing season (Section 4.14.2.1). In addition, Alternative F has the highest number of HFEs (38.1) of all alternatives, including a 1-day HFE in early May in all years without a sediment-triggered spring HFE. In addition, there would be an annual 7-day 25,000-cfs flow at the end of June that would occur during prime fishing months, which would also adversely impact fishing. The maximum number of days HFEs could disrupt fishing in any year would be 8, under Alternative F (if a spring HFE and fall HFE were conducted in the same calendar year).

An anticipated mean annual loss of 919 day-use rafting opportunities in Glen Canyon due to HFEs (Figure 4.10-1) is the largest such loss of any alternative and about 20 times that of Alternative A (loss of 49 rafting opportunities). In addition, the large number of HFEs in Alternative F would tend to increase erosion of sediment terraces in the Glen Canyon reach that support recreation facilities and campsites.

Under the steady flows of Alternative F, whitewater boaters would not be affected by daily flow fluctuations (FI = 1.0). With most daily flows near or above 8,000 cfs (NI = 0.71), navigability is expected to be higher than under Alternatives A, B, D and E and lower than under Alternatives C and G. Thus, conditions are anticipated to be satisfactory for boaters most of the time. With a high number of HFEs and steady monthly flows, Alternative F has a high likelihood of increasing campsite area (CAI = 0.41) (Figure 4.10-1). Steady daily flows would result in predictable availability of campsites. Usable campsite area would be reduced somewhat compared to Alternative G, due to high seasonal flows in March through June under Alternative F. Because Alternative F has lower flows in summer and fall months, that alternative may result in greater useable camping area during those months than under Alternative G.

There would be a small increase (6%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A or any other LTEMP alternative (average 38.1 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

There are no experimental elements in this alternative, other than HFEs, that could affect recreation.

In summary, Alternative F would have the greatest number of HFEs of all alternatives that could affect fishing and boating. In addition, angler satisfaction with flow levels under Alternative F is anticipated to be lowest of all alternatives due to high flows during the peak fishing season. The fewest large trout are expected under this alternative, but highest catch rates. Very few navigability concerns would exist from low flows and no safety or convenience concerns from daily fluctuations. However, the most lost rafting trips due to HFEs would occur, about 20 times the number under Alternative A. Alternative F is expected to be the second most beneficial of all alternatives with respect to increasing camping area due to the effects of HFEs and reduced erosion. It would have no interference with recreation from testing and implementing experimental actions beyond those related to HFEs.

4.10.3.7 Alternative G

Alternative G would have the second-lowest number of large trout (700 fish), but trout abundance and angler catch rates would be high (Section 4.5.3.7). Fishing would be disrupted during HFEs, and the number of HFEs under Alternative G (24.5) is much higher than under Alternative A (5.5). The maximum number of days that HFEs could disrupt fishing in any year would be 18 under Alternative G (if a spring HFE and extended-duration fall HFE were conducted in the same calendar year). Angler satisfaction related to flow levels and fluctuations under this alternative is expected to be slightly less than that under Alternative A.

The relatively high number of HFEs under this alternative (including proactive spring HFEs and extended-duration fall HFEs) would result in an anticipated annual loss of 512 visitor day-rafting opportunities in Glen Canyon over the LTEMP period (Figure 4.10-1); this is more than 10 times larger than under Alternative A (loss of 49 rafting opportunities). The number of HFEs would result in a higher tendency to erode sediment terraces that support recreation facilities and campsites compared to all alternatives but Alternative F.

Under the steady flows of Alternative G, whitewater boaters would not be affected by daily flow fluctuations (FI = 0.98), and the steady monthly flows would be consistently above 8,000 cfs, reflecting high navigability (NI = 0.96). Because of the high number of HFEs under Alternative G, and its steady monthly and daily flows, it has the highest likelihood of any alternative of increasing campsite area (CAI = 0.45) (Figure 4.10-1).

There would be a slight increase (2%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 24.5 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to HFEs, Alternative G includes experimental testing of mechanical removal of trout in the Little Colorado Reach; and testing and implementation of TMFs. The impacts of mechanical trout removal activities would be similar to those described under Alternative A. Based on the expected number of trout in the Little Colorado River reach, Alternative G has an estimated three such removals, the greatest number triggered during the LTEMP period of all alternatives (Table 4.9-2).

TMFs are intended to decrease trout abundance, which might reduce angler catch rate; however, it could also result in an increased number of larger fish in the fishery in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. Based on the anticipated higher trout recruitment levels, Alternative G is expected trigger TMFs in 11 of 20 LTEMP years (Table 4.9-2), the highest number of all alternatives.

In summary, angler satisfaction with flow levels and fluctuations would be similar to that under Alternative A. Alternative G would have fewer large trout than Alternative A, but catch rates would be higher. Very few navigability concerns would exist from low flows and no safety or convenience concerns from daily fluctuations. There would be about 10 times more lost rafting trips due to HFEs than under Alternative A. Alternative G is expected to be the most beneficial of all alternatives with respect to increasing camping area due to the effects of HFEs and reduced erosion. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.11 WILDERNESS

Issue: How do the alternatives affect wilderness and visitor wilderness experience?

Impact Indicators:

- Opportunities for solitude at campsites and on the river
- Preservation of natural conditions as reflected by naturalness of flow
- Rafters' time available for onshore exploration
- Visual and noise disturbances from administrative uses

This section presents the potential impacts on wilderness and visitor wilderness experience. Although flows from Glen Canyon Dam would not be considered a prohibited use under the Wilderness Act, impacts are disclosed within this section for the purposes of their implications to NPS wilderness management. Background information on the wilderness qualities evaluated in this analysis appears in Section 3.15.

As stated in Section 3.11, there is proposed wilderness in both Glen Canyon and the Grand Canyon within the Colorado River Ecosystem. The NPS has an obligation to manage the Colorado River corridor through GCNP to protect and preserve the resource in a wild and primitive condition and provide a wilderness river experience (as described in the 2006 Colorado River Management Plan). The proposed wilderness designation does not include areas upstream from Lees Ferry (including Glen Canyon Dam); moreover, the NPS management for wilderness values must remain consistent with the Section 1802 (b) of the GCPA. There are also references to Section 4.10: Recreation, Visitor Use, and Experience.

4.11.1 Analysis Methods

The analysis of impacts on wilderness and visitor wilderness experience downstream of Glen Canyon Dam was based on an assessment of alternative-specific differences in four indicators of the quality of visitor wilderness experience: opportunities for solitude at campsites and on the river; preservation of natural conditions as reflected by naturalness of flow; opportunities for experiencing wilderness as indicated by the amount of time rafters have for exploration; and visual and noise disturbances. These indicators are evaluated qualitatively and comparatively as they relate to the differing properties or features of the seven alternatives.

The effects of the alternatives on campsite crowding and its effect on visitor wilderness experience was evaluated through consideration of the tendency of flow patterns and experimental flows (mainly HFEs) under the various alternatives to build beaches and thus potentially increase campsite area. The likelihood of rafters encountering other groups at rapids was evaluated based on the expected frequency of daily flows less than 8,000 cfs, a flow level associated with rafting delays at rapids as rafters scout conditions or wait for higher flows. Flows of 8,000–9,000 cfs have been identified by commercial guides as the minimum level necessary to safely run the river with passengers (Bishop et al. 1987; Stewart et al. 2000).

The naturalness of flows was evaluated by determining the magnitude of daily flow fluctuations under alternatives as compared to fluctuation levels perceived to be less natural, generally greater than 10,000 cfs as identified by Bishop et al. (1987). Stewart et al. (2000) found that daily fluctuations of 5,000–8,000 cfs under MLFF were not an issue for most recreational use, but they did not address fluctuations above 10,000 cfs. Opportunities for rafters to explore attraction sites or enjoy personal time at camp were evaluated by determining the effects of flow on river travel duration and the amount of off-river time available each day. Finally, the effects of noise and visual disturbance of wilderness values was evaluated by considering the number of HFEs, TMFs, trout removals, and the relative number of administrative trips expected under the alternatives.

The metrics described in Section 4.10 were used as input to the evaluation of effects on wilderness experience. The potential for beach building used the Camping Area Index to evaluate the effects of campsite availability and size on potential crowding and opportunities for solitude (Figure 4.10-1a); the Navigation Risk Index was used to evaluate potential crowding at rapids (Figure 4.10-1d); the Fluctuation Index was used to evaluate the naturalness of flows(Figure 4.10-1c); and the Time-Off-River Index was used to evaluate the opportunity for onshore exploration (Figure 4.10-1b). The effects of HFEs, TMFs, trout removal, and other experimental actions were evaluated from estimates of the expected frequency of such actions for the alternatives. Using these metrics and supporting information, it was possible to rank the alternatives with respect to their relative effects on associated wilderness values. The details of the methodology used to produce metric values and detailed results are presented in Appendix J.

4.11.2 Summary of Impacts

In Section 3.15, wilderness character is described as having four qualities: untrammeled, natural, undeveloped, and providing for outstanding opportunities for solitude or a primitive and unconfined form of recreation. In describing the wilderness values and visitor experiences within GCNP that are to be preserved and protected, GCNP's General Management Plan states that "Visitors traveling through the canyon on the Colorado River should have the opportunity for a variety of personal outdoor experiences, ranging from solitary to social. Visitors should be able to continue to experience the river corridor with as little influence from the modern world as possible. The river experience should help visitors to intimately relate to the majesty of the canyon" (NPS 1995).

Dam operations and management activities considered under LTEMP alternatives can affect these wilderness values and the quality of the wilderness river experience for river visitors. As dam operations affect beach retention or building, operations under the alternatives can affect campsite crowding and solitude. Similarly, low daytime flows less than 8,000 cfs can increase crowding at rapids. Although these are conceivable effects on wilderness experience and have been modeled for the alternatives, such effects would detract only slightly from an overall wilderness experience in the study area, and differences in the effects of alternatives would be difficult to discern.

Wilderness experience may also be affected by high daily fluctuations that appear to be greater than what would occur naturally. Fluctuations in excess of 10,000 cfs have been identified as creating less natural conditions on the river (Bishop et al. 1987). TMFs and HFEs would also present less natural conditions to visitors. However, daily fluctuations under MLFF and the proposed alternatives are generally constrained to near or less than 10,000 cfs and thus would have at most a small effect on perceptions of naturalness, differences in which would be difficult to discern among fluctuating flow alternatives; the steady flow Alternatives F and G would have no such effects.

Overall flow level can also affect the wilderness experience through effects on the duration of rafting trips and thus the time available for onshore exploration. However, because there is little difference among the alternatives in time off river (Figure 4.10-1b), this measure is not discussed further in this analysis.

Finally, resource management actions, (i.e., administrative actions) including experimental vegetation treatment under all alternatives but Alternative A; mechanical removal of trout, which is allowed under some alternatives; and other experimental work and administrative trips common to all alternatives can affect visitor experience by increasing encounter rates, placement and use of equipment, and noise from motorized equipment. Such effects would be infrequent and short term and would affect relatively few visitors. Vegetation actions, even though they would conform to minimum tool use requirements, may have short-term negative effects during disturbance but long-term positive effects on wilderness by returning native vegetation and hence wilderness character. Effects on wilderness experience of the LTEMP alternatives are summarized and compared in Table 4.11-1 and analyzed in the discussions that follow.

Campsite crowding has been reduced since the implementation in 2006 of the CRMP (NPS 2005a), but campsite area and campsite size was decreasing (Kaplinski et al. 2010) prior to adoption of the HFE protocol in 2011 (Reclamation 2011b). Alternatives that do not reverse the trend of loss in campsite area eventually would have an adverse effect on wilderness qualities because of increases in crowding at remaining campsites. On the basis of the number of HFEs anticipated under each of the alternatives (Section 4.3), Alternatives F and G are expected to result in the greatest benefit to visitor wilderness experience with respect to opportunity for solitude, because of a greater likelihood of increasing and retaining campsite area (Section 4.10.2). Alternatives C, D, and E rank just below Alternatives F and G, while Alternatives A and B rank lowest with regard to camping area as a consequence of having the fewest HFEs. Under Alternative A (the No Action Alternative), HFEs would not be implemented after the HFE protocol expired in 2020.

On the basis of allowable within-day fluctuation, Alternatives B and E would have more frequent occurrences of very low flows (about 60% of days), including in the periods of peak recreational use, and therefore would tend to result in more crowding at rapids as rafters stop to

TABLE 4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Declining camping area following cessation of HFEs would reduce opportunity for solitude; intermediate effects on crowding at rapids and levels of fluctuations; lowest disturbance from experimental actions.	Compared to Alternative A, similar decline in camping area, somewhat more crowding at rapids, greatest level of fluctuations, greater disturbance from non-flow actions, especially under experimental hydropower improvement flows.	Compared to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, similar crowding at rapids, similar level of fluctuations, greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, less crowding at rapids, no fluctuations, greater disturbance from non-flow actions, but no mechanical removal of trout.	Compared to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Campsite crowding as indicated by the camping area index (CAI)	No change from current conditions; lack of HFEs after 2020 would lead to continued declining size and number of campsites (CAI = 0.14 out of 1) and could result in further crowding and adverse effects on solitude.	Compared to Alternative A, continued declining trend in campsite area (CAI = 0.15) could result in crowding and adverse effects on solitude.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.38) could reduce crowding and improve solitude.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.36) could reduce crowding and improve solitude.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.30) could reduce crowding and improve solitude, but would be lower than other alternatives except Alternatives A and B.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.41) could reduce crowding and improve solitude. Steady flows also would aid trip planning, helping to avoid crowding.	Compared to Alternative A, greatest increase in campsite area (CAI = 0.45) could reduce crowding and improve solitude. Steady flows also would aid trip planning, helping to avoid crowding.

TABLE 4.11-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Encounters with other groups at rapids due to low flows (8,000 cfs) as indicated by the navigation index (NI)	No change from current conditions; intermediate rank among alternatives; NI = 0.50 out of 1.	More encounters than Alternative A; NI = 0.39.	Fewer encounters than Alternative A; NI = 0.75.	Similar effect as Alternative A; NI = 0.45.	Most encounters due to highest frequency of low flows; NI = 0.37.	Fewer encounters than Alternative A because steady flows mostly above 8,000 cfs; NI = 0.71.	Fewest encounters because of steady flows nearly always above 8,000 cfs; NI = 0.96.
Effect of daily fluctuations as indicated by the fluctuation index (FI)	No change from current conditions; intermediate effect among alternatives, FI = 0.79 out of 1.	Highest daily fluctuations, FI = 0.42.	Almost no effect, FI = 0.93.	Similar to Alternative A, FI = 0.74.	Second-highest daily fluctuations, FI = 0.57.	No effect; steady daily flows, FI = 1.0.	No effect; steady daily flows, FI = 0.98.
Disturbance from non-flow actions: vegetation management, mechanical removal of trout, and administrative trips	No change from current conditions; no vegetation treatments, few mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments; and few mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments and more mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments and more mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments and potentially more mechanical removals of trout.	Compared to Alternative A, less impact due to absence of mechanical removals of trout, but greater effects due to vegetation treatments.	Compared to Alternative A, greater impacts due to vegetation treatments and more mechanical removals of trout.

scout rapids or wait for flows to rise. Alternatives D and A would be similar to each other and comparable to current conditions (about 50% of days with low flows), while Alternatives F, C, and G would have the fewest days with low flows (about 5% to 30% of days), and would result in the lowest chances of encountering other groups. Although these comparisons are easily made on the basis of the flow patterns of the alternatives, the actual effects on crowding at rapids may be small overall, and small differences noted between alternatives may not be significant.

Daily flow fluctuations in excess of 10,000 cfs have been identified as creating less natural conditions on the river. The effect of such flow fluctuations on wilderness experience was evaluated using the fluctuation index (Section J.2.3 in Appendix J) developed from maximum "tolerable" fluctuations preferred by whitewater rafters (Table 3.10-2), which are generally less than 10,000 cfs and depend on overall flow level (Bishop et al. 1987). The fluctuation index is presented in Section 4.10, where it is used to evaluate effects of fluctuations on whitewater rafting. It is used here as a surrogate for effects on perceived natural conditions in the Grand Canyon. Alternatives F and G, which employ steady flows, have fluctuation index values near 1.0, indicating no within-day fluctuations. Fluctuating flow Alternatives A, C, and D would be similar to each other, with most fluctuations within the preferred range; they would have fluctuation index values of 0.79, 0.93, and 0.74, respectively. Alternatives B and E would have the lowest fluctuation index values, indicating the lowest frequency of fluctuations within the preferred range (Figure 4.10-1). Alternative D would include testing of macroinvertebrate production flows during weekend days from March through August, and these steady flows would reduce any impacts of fluctuations on wilderness experience on those days. Because most daily fluctuations under all alternatives are below the 10,000-cfs level (flows ≥10,000 cfs were identified as being perceived as less natural by Bishop et al. 1987), the fluctuation index, which was developed for whitewater rafting for effects of fluctuations on such factors as navigation and camping, is not a perfect surrogate for evaluating perceived naturalness of flows. Visitors would be expected to notice that high daily fluctuations are not natural; however, the overall effects of such perceptions on wilderness experience are likely fairly small.

A metric (time off river) was developed to quantify the relative amount of time rafters would have to explore and enjoy wilderness at the end of each day (Section 4.10.1). Roberts and Bieri (2001) demonstrated that groups spent 50% less time off river at a flow of 8,000 cfs, compared to a flow of 19,000 cfs. Evaluation of the flow patterns of the LTEMP alternatives demonstrated that there would be very little difference among alternatives for this metric, except under Alternative F, which has elevated flows during the peak boating season. This similarity among alternatives is likely due to the fact that each has similar mean annual flows of between 10,000 and 15,000 cfs.

Non-flow experimental actions, including mechanical removal of trout, experimental vegetation treatments, and administrative trips related to monitoring and data collection needed for the GCDAMP would also present less natural conditions to visitors related to noise and visual disturbances. Vegetation treatments, proposed by NPS as an experimental, pilot effort to determine the effectiveness of vegetation control and treatment efforts, would occur under all alternatives except for Alternative A. They would temporarily adversely affect wilderness experience while the activities were ongoing and until treatments were discontinued, either because they had achieved a level of success that produced natural vegetation communities, or because they were ineffective.

Alternative A would have the lowest impacts from non-flow experimental actions, because vegetation treatment is not included in the alternative. Alternative F would have impacts that were slightly higher than Alternative A, but lower than the remaining alternatives, because this alternative does not employ mechanical trout removal. Alternatives B, C, D, E, and G would have the highest levels of such impacts, which would be comparable under these alternatives.

Considering the effects of flow fluctuation overall, the steady flow Alternatives F and G would rank as having generally lower adverse effects on wilderness experience than the fluctuating flow alternatives, because the latter alternatives have effects on a daily basis. This advantage is reduced somewhat, but not entirely, by the higher frequency of HFEs under Alternative F and of HFEs and TMFs under Alternative G as compared to the fluctuating flow Alternatives A–E. Of the fluctuating flow alternatives, Alternative A would have the lowest effects from fluctuating flows due to moderate daily fluctuations, few HFEs, and no TMFs. Alternatives B, C, D, and E would have comparable effects from fluctuations, with Alternative B having the greatest effect from high daily fluctuations, but the fewest HFEs of these alternatives.

Considering sand retention and potential increase in sandbar area, which is also an effect of flows and flow fluctuations, benefits related to sand retention and increases in sandbar area would be lowest under Alternatives A and B, which would have relatively few HFEs that would build bars and relatively high fluctuating flows that would erode bars. Benefits would be intermediate under Alternatives C, D, and E, which have more HFEs to build sandbar area than Alternatives A and B. Benefits would be greatest under Alternatives F and G, which would have steady flows and the most frequent HFEs. Crowding and loss of solitude would decrease with increasing sandbar area.

While the metrics discussed above provide an analytical tool to evaluate and differentiate the LTEMP alternatives with regard to effects on visitor wilderness experience, actual differences for most visitors would be small and many of the disturbances evaluated—including HFEs, TMFs, mechanical trout removals, and vegetation management—would be infrequent, short-term actions that would not affect most visitors. In addition, few visitors would be expected to experience more than one of these disturbances, as a given action of one type typically excludes the other actions at a given time (e.g., a TMF would not occur at the same time as an HFE or likely within the time period of a single trip).

4.11.3 Alternative-Specific Impacts

The following Section provides descriptions of impacts summarized above as they are expected to occur under each of the LTEMP alternatives. The alternatives are compared in terms of the relative rankings of the various wilderness experience effects and measures considered, rather than in absolute terms.

4.11.3.1 Alternative A (No Action Alternative)

Under Alternative A (the No Action Alternative), the HFE protocol would expire in 2020. It is expected that implementation of the protocol up to its expiration would help reverse the ongoing trend of declining campsite area, but the declining trend would resume after the protocol expired. Any increase in crowding would reduce opportunities for solitude and primitive, unconfined recreation under this alternative.

Alternative A, with a navigation index of 0.50 (Figure 4.10-1), ranks in the middle of the LTEMP alternatives, indicating a relatively high tendency for low flows to lead to encountering other groups at rapids under Alternative A. The navigation index is a seasonally weighted measure of the frequency of minimum daily flows greater than 8,000 cfs, identified as the flow below which navigation risks increase (Appendix J.2.2).

Similarly, Alternative A ranks in the middle of alternatives with regard to daily fluctuation levels, with a fluctuation index of 0.79 (Figure 4.10-1); a majority of days would be within the daily range of fluctuations preferred by whitewater rafters (Section J.2.3 in Appendix J), which would also maintain a sense of naturalness as identified by Bishop et al. (1987). This ranking is consistent with allowed daily fluctuations under the respective alternatives. With respect to experimental flows, Alternative A has the lowest projected number of HFEs and no TMFs that would negatively affect wilderness experience.

Alternative A would have the second lowest impacts on wilderness experience from non-flow actions overall among the alternatives. Alternative A has no TMFs, a low expected number of mechanical removal trips, and no experimental vegetation treatments. The number of administrative trips expected under this alternative would be comparable to that of other alternatives.

In summary, Alternative A has the lowest potential to increase campsite area and a corresponding decrease in visitor solitude, and a moderate tendency for crowding at rapids due to periods of lower flows. Alternative A would have moderate adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and has the lowest adverse effects from non-flow experimental actions on wilderness experience as a result of having the lowest combined number of such actions.

4.11.3.2 Alternative B

Alternative B would have a relatively low potential to retain and build sandbar area, similar to that for Alternative A, and would be expected to continue a long-term trend of increasing campsite crowding due to erosion. The low tendency to retain sand and build beaches is attributable to the low number of projected HFEs over the 20-year LTEMP period (an average of 7.2) and high daily fluctuations. Any increase in crowding would reduce opportunities for solitude under this alternative.

Alternative B, with a navigation index of 0.39 (Figure 4.10-1), has one of the highest tendencies for low flows to lead to encountering other groups at rapids. Any such effect, however, would lead to only small effects on wilderness experience, because frequency of encounters would be slightly increased, short term, and low impact.

Alternative B, with a fluctuation index of 0.42 (Figure 4.10-1), would have the fewest days within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987), resulting in a high relative potential to reduce a sense of naturalness among the alternatives. With respect to experimental flows, Alternative B has the second lowest projected number of HFEs and a moderate number of TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative B would be higher than under Alternative A, but comparable to, or in the case of mechanical removals of trout less than, those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short-term and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative B has the second lowest potential to increase campsite area and preserve visitor solitude, while having among the highest tendencies for crowding at rapids due to low flows. Alternative B would have among the highest adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to, or lower than, most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.3 Alternative C

Alternative C is expected to have a relatively high potential to retain sand and build sandbar area (exceeded only slightly by Alternatives F and G) and is expected to reverse the trend in declining campsite area. This high potential results from the high frequency of HFEs (an average of 21.3 over the LTEMP period) and moderate within-day fluctuations in flow. This increase in camping area would improve opportunities for solitude.

Alternative C, with a navigation index of 0.75 (Figure 4.10-1), has a relatively low tendency for encounters at rapids, and thus a relatively low potential to affect solitude.

Alternative C, with a fluctuation index of 0.93 (Figure 4.10-1), ranks third among alternatives; most days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a correspondingly low potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative C has the second-highest projected number of HFEs and a moderate to high number of TMFs that would negatively impact wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative C would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative C has a relatively high potential to increase campsite area and preserve visitor solitude, while having a low tendency for crowding at rapids due to low flows. Alternative C would have among the lowest adverse effects on wilderness experience from daily flow fluctuations and experimental flows, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.4 Alternative D (Preferred Alternative)[26]

Alternative D is expected to have a relatively high potential to retain sand and build sandbar area, similar to Alternatives C, F, and G, and is expected to reverse the trend in declining campsite area. This high potential results from a high number of projected HFEs over the next 20 years (an average of 21.1), similar to Alternative C, and moderate within-day fluctuations. This increase in camping area would improve opportunities for solitude.

Alternative D, with a navigation index of 0.45 (Figure 4.10-1), would be comparable to Alternative A with regard to encounters at rapids, and would represent little change from current conditions.

Alternative D, with a fluctuation index of 0.74 (Figure 4.10-1), ranks fifth among alternatives, just below Alternative A; a majority of days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a correspondingly low potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative D has a high number of HFEs (tied with Alternative C) and the second-highest number of TMFs, which could negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative D would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative D has a relatively high potential to increase campsite area and preserve visitor solitude, while having a moderate tendency for crowding at rapids due to low

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[26] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on wilderness.

flows. Alternative D would have moderate adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.5 Alternative E

Alternative E is expected to have a moderate potential to retain sand and build sandbar area, slightly lower than Alternatives C, D, F, and G, and would be similarly expected to reverse the trend in declining campsite area. This moderate potential results from a medium number of projected HFEs over the next 20 years (an average of 17.1) and daily fluctuations somewhat higher than Alternatives A, C, and D, but lower than Alternative B. This increase in camping area would improve opportunities for solitude under this alternative.

Alternative E, with a navigation index of 0.37 (Figure 4.10-1), would have the highest tendency for low flows to lead to encountering other groups at rapids relative to the other alternatives.

Alternative E, with a fluctuation index of 0.57 (Figure 4.10-1), ranks sixth among alternatives, above only Alternative B; about half of days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a high relative potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative E has a moderate number of HFEs and a moderate number of TMFs that would negatively affect wilderness experience

The number of non-flow experimental actions and administrative trips under Alternative E would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative E has a moderate potential to increase campsite area and preserve visitor solitude, while having a relatively high tendency for crowding at rapids due to low flows. Alternative E would have relatively moderate to high adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.6 Alternative F

Alternative F is expected to have the second-highest potential to retain sand and build beach area and would be similarly expected to reverse the trend in declining campsite area. This high potential results from a high number of projected HFEs over the next 20 years (an average of 38.1) and steady flows. This increase in camping area would improve opportunities for solitude under this alternative. Steady flows under this alternative will aid in trip planning, which will also help avoid crowding.

Alternative F, with a navigation index of 0.71 (Figure 4.10-1), would have lower tendency for low flows to lead to encountering other groups at rapids than other alternatives, except Alternatives C and G.

Alternative F, with a fluctuation index of 1.0 (Figure 4.10-1), ranks highest among alternatives; essentially all days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and effectively no potential to reduce a sense of naturalness due to high daily flow fluctuations under this steady-flow alternative. With respect to experimental flows, Alternative F has the highest number of HFEs but no TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative F would be higher than under Alternative A, but lower than those under other alternatives because this alternative would not feature mechanical trout removal. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative F has a high potential to increase campsite area and preserve visitor solitude, while having a low tendency for crowding at rapids due to low flows. Alternative F would have no adverse effects from daily flow fluctuations but some effects from the highest number of HFEs on wilderness experience, and is lower than most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.7 Alternative G

Alternative G is expected to have the highest potential to retain sand and build sandbar area and would be most likely of all alternatives to reverse the trend in declining campsite area. This high potential results mainly from a high number of projected HFEs over the next 20 years (an average of 24.5) and steady flows. This increase in camping area would improve opportunities for solitude under this alternative. Steady flows will aid in trip planning, which will also help avoid crowding.

Alternative G, with a navigation index of 0.96 (Figure 4.10-1), would have the lowest tendency of all alternatives for low flows to lead to encountering other groups at rapids.

Alternative G, with a fluctuation index of 0.98 (Figure 4.10-1), ranks second among alternatives, slightly below Alternative F; nearly all days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and effectively no potential to reduce a sense of naturalness due to high daily flow fluctuations under this steady-flow alternative. With respect to experimental flows, Alternative G has the second-highest number of HFEs and highest number of TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative G would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative G has a high potential to increase campsite area and preserve visitor solitude, while having the lowest tendency for crowding at rapids due to low flows. Alternative G would have no adverse effects from daily flow fluctuations, but some effects from the second-highest number of HFEs on wilderness experience; it is comparable to all alternatives except Alternatives A and B with respect to adverse effects of HFEs and comparable to other alternatives with respect to effects of non-flow experimental actions on wilderness experience.

4.12 VISUAL RESOURCES

Issue: How do the alternatives affect visual resources?

Impact Indicators:

- Exposure of lake deltas in Lake Mead and Lake Powell
- Changes in vegetation and sandbar size

This section describes the assessment of the potential effects of the alternatives on visual resources, concentrating on changes that could occur to the water, select geological features, and areas of riparian vegetation along the shore lines of the Colorado River, Lake Powell, and Lake Mead.

Visual resources are important to visitor enjoyment of GCNRA, GCNP, and LMNRA, and the conservation of visual resources is an important component of federal management activities for these areas. For this reason, it is important to understand how dam operations and non-flow management actions may affect visual resources within the project area. Indictors of effects on visual resources include the height of the calcium carbonate ring surrounding Lake Mead and Lake Powell, the exposure of lake deltas in Lake Mead and Lake Powell, the exposure of Cathedral-in-the-Desert in Lake Powell, and potential impacts associated with changes in vegetation and water color, clarity, and surface appearance.

Calcium carbonate deposits form at the water line and are typically visible at reservoir elevations below full pool, where they create a bathtub ring effect. They are generally lighter in color than the walls without calcium carbonate deposits. This creates visual contrast that may result in visual impacts. The calcium carbonate deposits around both Lake Powell and Lake Mead will be more or less exposed as reservoir levels rise and fall; however, the exposure will be most affected by future hydrology. In order to quantify the extent of visibility of the calcium carbonate rings, the average end-of-month elevation of each reservoir over the 20-year LTEMP period was modeled, and from this the potential range in height of the exposed calcium carbonate ring (the distance from the top of the ring to the water level) was determined. Projected elevations were compared against both reservoirs at full pool. Lake Powell is considered at full pool at 3,700 ft AMSL. Lake Mead is considered at full pool at 1,221 ft AMSL.

Our analysis indicates that the reservoir elevations would vary very little under the different alternatives, resulting in very little difference in the potential maximum height of the calcium carbonate ring. For Lake Powell, the potential difference in the maximum height of the ring varies approximately 1 ft among the alternatives for a short-term period within the year, but would be no different by the end of the water year. For Lake Mead, the potential difference in the maximum height of the ring varies approximately 3 ft for a short-term period within the year, but would be no different by the end of the water year among the alternatives. The calcium carbonate deposits produce a visual contrast regardless of their height and size and make up only a portion of the view in both reservoirs, and the overall difference in visual impacts among the alternatives as a result of exposure of the rings would be negligible.

Lake deltas appear as expansive, eroding sediment deposits that become more visible as the water level in the reservoir decreases. They are considered a visual detraction (Reclamation 2007a). The size of a lake delta is directly affected by the mass of sediment delivered to the delta, and its exposure is directly affected by reservoir elevation. Lake deltas within Lake Powell and Lake Mead will be more or less exposed as reservoir levels fall and rise; however, the exposure of the lake deltas will be most affected by future hydrology. The increased visibility of lake deltas creates increased visual contrast and may result in visual impacts. In order to quantify the extent of the visibility of lake deltas, the average end-of-month elevation of each reservoir over the 20-year LTEMP period was modeled to determine if lake deltas would be more or less exposed in each of the reservoirs.

The analysis indicates that Lake Powell elevations would vary approximately 1 ft among the alternatives, while Lake Mead elevations would vary approximately 3 ft among the alternatives. Lake deltas produce visual contrast regardless of their height and size and make up a very small part of the views in both reservoirs. On the basis of predicted variation in reservoir elevations, there would be little, if any, difference in the exposure of lake deltas in either reservoir among the alternatives, and the overall difference in visual impact among the alternatives as a result of exposure of lake deltas would be negligible.

Cathedral-in-the-Desert is a prominent geological feature in Lake Powell that attracts many visitors when exposed. The feature is exposed when the Lake Powell reservoir elevation is ≤ 3,550 ft AMSL (Reclamation 2007a). Because of the attention Cathedral-in-the-Desert receives when it is exposed, the exposure of this feature could be perceived as a positive impact or benefit. To determine the potential exposure of Cathedral-in-the-Desert, the average number of months per year that Lake Powell's end-of-month elevation was ≤ 3,550 ft AMSL over the

20-year LTEMP period was modeled. Our analysis indicates that Cathedral-in-the-Desert could be exposed an average of 2 months per year over the 20-year LTEMP period under all alternatives, and the overall difference in visual impact between the alternatives would be negligible for Cathedral-in-the-Desert and similar attractions within the reservoir basin.

Vegetation plays an important role in the scenic experience along the Colorado River. Vegetation increases the visual interest of many places where it occurs by adding variety in color and texture in contrast to the river, rocks, and bare canyon walls. Flow variations and non-flow management actions can alter the type and frequency of vegetation along the corridor (see Section 3.6.2 and Section 4.6). Changes in vegetation could result in different levels of color and texture in contrast to the surrounding landscape, but it is difficult to predict how this could affect a visitor's visual experience and is not expected to vary significantly among alternatives. It is not possible to predict what types of vegetation are more appealing than others to recreationists. Individuals are often influenced by their personal experiences and/or expectations, and what is visually pleasing to one individual may not be to another. Potential impacts on vegetation were assessed based on professional judgment and the riparian vegetation assessment presented in Section 4.6.

Although frequent visitors to the Canyons, such as Tribal members, river guides, scientists, and anglers, will likely notice a change in plant states and sandbar size, it is not certain that an individual participating in a once-a-year or once-in-a-lifetime river trip will notice any change unless there are vegetation management activities underway during visitor trips. Visitors standing at scenic overlooks with views of the river may notice vegetation or sandbars in the corridor, but they will be unlikely to notice a change in vegetation state or sandbar size from these locations, given their distance from the river. Therefore, visual impacts on the Canyons from changes in vegetation or sandbar size are expected to be negligible under all alternatives.

NPS management actions that are being proposed in the river corridor of Glen and Grand Canyons as well as on Hualapai lands, such as nonnative plant removal, native plant revegetation, and mitigation at cultural sites, may have effects on the visual environment. These effects are associated primarily with the alteration of the forms, colors, and textures of vegetation, both immediately after implementation of management activities and over longer time periods, because of changes in species composition, but, as discussed above, the visual effects of changes in vegetation type and cover would be negligible.

Based on this analysis, the effects are considered negligible and would not vary among the alternatives.

4.13 HYDROPOWER

This section describes the potential impacts of changes in Glen Canyon Dam operations on the economic value of the powerplant's capacity and energy production. Impacts are measured in terms of changes in regional power system capacity expansion pathways[27] and overall system-level electricity production costs. The amount of generation and associated economics at the Hoover Dam Powerplant is analyzed separately. This section discusses how changes in system resources and operations affect both wholesale electricity rates paid by utilities that purchase firm capacity and energy from WAPA. This section also presents analysis on the retail electricity rates produced by the Glen Canyon Dam Powerplant.

Issue: How do alternatives affect hydropower resources?

Impact Indicators:

- Changes in the amount (MWh) and dollar value of hydropower generation at Glen Canyon Dam
- Changes in SLCA/IP firm capacity
- Changes in capital and operating costs that WAPA's customers incur to serve their loads
- Changes in wholesale rates that WAPA charges its firm electric service customers
- Changes in residential electricity bills of WAPA's customers
- Changes in powerplant generation and economics at Hoover Dam.

4.13.1 Analysis Methods

This section describes the methods used to estimate the impact of alternative Glen Canyon Dam operating criteria on the economic value of its hydropower resources, to compute changes in the rate that WAPA charges its firm electric service (FES) customers, and to estimate the impacts on retail electricity rates charged by entities that purchase power from the Salt Lake City Area Integrated Projects (SLCA/IP or federal preference power). This section also describes the methods used to estimate the possible indirect impact of alternative operating criteria at Glen Canyon Dam on Hoover Dam generation and economics.

The LTEMP hydropower resources impact analysis was largely an economic analysis rather than a financial analysis. A financial analysis focuses on the revenues and costs accrued by a particular entity, including transfer payments, such as power transactions, taxes, and insurance. It also includes payments made by individual entities for previous investments. In contrast, an economic analysis focuses on societal costs and benefits. Transfer payments among entities are excluded because the total net change to society of these transactions is zero; that is, the amount paid by the buying entity equals the amount received by the selling entity. Also excluded from economic costs are past investments, such as those to construct power plants, because these expenditures have already been incurred on society and cannot be recovered. Similar to other power systems EIS analyses performed by Argonne, the economic analysis performed for LTEMP estimates changes to the U.S. economy as the result of altering operating criteria at Glen Canyon Dam. These economic costs include expenditures to build and operate new capacity in the future to replace Glen Canyon Dam Powerplant lost capacity and both fuel and variable

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[27] A capacity expansion pathway is a specification of the size, timing, and type of generating units to be constructed over a specified planning horizon.

operation and maintenance (O&M) costs associated with altering the dispatch of Western Interconnection generating units. A financial analysis was performed for the LTEMP EIS to estimate the wholesale (see Section 4.13.1.2) and retail rate impacts (see Section 4.13.1.3) on individual affected entities (e.g., individual FES utilities and their retail customers).

4.13.1.1 Hydropower Resource and Capacity Expansion Impacts

For each of the proposed alternative operating criteria, the hydropower impact analysis estimated the net present value (NPV) of the cost of meeting future energy and capacity demands of utilities (customers) that have long-term firm (LTF) contracts to purchase power from WAPA's SLCA/IP facilities (Section 3.13) and compared these costs to the NPV of costs under the existing operating criteria (Alternative A, the No Action Alternative).

A number of models and spreadsheet tools were used for the analysis, including:

- *Colorado River Simulation System (CRSS)* simulated future monthly operations for the six large SLCA/IP facilities that include the Seedskadee Project (Fontenelle) and the five Colorado River Storage Project (CRSP) facilities; namely, Glen Canyon Dam, Flaming Gorge Dam, and the Aspinall Cascade (Blue Mesa, Morrow Point, and Crystal Dams).

- *Sand Budget Model (SBM)* scheduled the type and timing of HFEs at Glen Canyon Dam and reallocated monthly water release volumes from CRSS, and revised monthly elevations to enable higher water releases during months with HFEs. Another type of experiment at Glen Canyon Dam, TMFs, were also added at this stage.

- *GTMax-Lite* optimized the economic value of hourly energy produced at the five largest CRSP power facilities based on monthly results from CRSS. This model determined an hour-by-hour pattern of both generation (in MWh) and water releases (in cfs) that satisfied the operating constraints imposed by each alternative, such as up/down ramp rates, maximum change in the release over a rolling 24-hour period, maximum hourly release, and others. This model consists of two configurations: one for Glen Canyon Dam and one for the remaining four CRSP facilities and Fontenelle.

- *AURORAxmp (Aurora)* simulated the operation of the modeled power system and projected hourly spot market prices in the Western Interconnection. The model was run in the capacity expansion mode to project system capacity expansion paths that would reliably meet future electricity demands, and in the unit dispatch mode to simulate powerplant unit operations to serve the load while minimizing total electricity production cost. The model was developed by EPIS, Inc., and is commonly used by utilities throughout the United States.

- *Other specialized models and spreadsheet models* developed for the LTEMP analysis included:
  - Representative Trace Tool: selected the most representative trace or hydrological future of all traces simulated by CRSS and the SBM.
  - Hydropower Outage Model: simulated unit outages, both scheduled maintenance and forced outages, at the six large SLCA/IP facilities.
  - Hourly Load Forecast Algorithm: determined hourly loads of WAPA's customers over the study period.
  - Firm Marketable Capacity spreadsheet: estimated the amount of firm capacity from all SLCA/IP facilities that WAPA could offer its customers at an assumed risk preference or exceedance level.

More detail on each model and tool can be found in Appendix K, Sections K.1.4 and K.1.5.

A number of simplifying assumptions were made for the hydropower analysis, as follows:

- The geographic scope of the analysis was limited to the service territories of utilities with which WAPA currently has LTF electricity contracts. Limiting the analysis to WAPA's customers allows the analysis to concentrate on the systems most affected by an LTEMP alternative with an adequate level of fidelity to obtain good estimates of economic impacts. In addition, the hourly economic value of energy which drives much of SLCA/IP operations was estimated by a tangential modeling task that encompasses the entire Western Interconnection.

- Given the amount of power generated at Glen Canyon Dam relative to the amount of electricity in the Western Interconnection power grid, the analysis assumes that the operation of Glen Canyon Dam does not have a significant influence on the marginal value of electricity at locations outside of the large utilities that WAPA serves.

- WAPA's customers are separated into two categories: large and small. Large customers, which comprise about 75% of firm capacity and energy sales, were modeled more rigorously than small customers. The eight largest customers are Deseret Generation and Transmission Cooperative (Deseret), the Navajo Tribal Utility Authority (NTUA), Salt River Project (SRP), Utah Associated Municipal Power Systems (UAMPS), Utah Municipal Power Agency (UMPA), Platte River Power Authority, Tri-State Generation and Transmission Association (Tri-State), and Colorado Springs Utilities (CSU). There are about 130 remaining "small customer" entities accounting for the remaining 25% of LTF sales. Individually, each small customer receives less than 2.5% of WAPA's total SLCA/IP LTF capacity and energy sales.

- The CRSS model was used to project operations under 105 monthly hydrological traces over a 48-year period from 2013 through 2060 for three sediment traces, namely, high, moderate, and low. Each trace contains a unique historical chronological time sequence of hydrological conditions. Therefore, hydrological conditions are deterministic, and it is extremely unlikely that any one trace will ever be repeated. Of these 105 traces, a common set of 21 was used to estimate the level of firm capacity of the CRSP plants and the Fontenelle powerplant. To estimate the hourly value of Glen Canyon Dam energy production, the AURORA model was run in dispatch mode using a representative hydrological trace. The trace chosen best met a set of criteria for being "representative," and included a significant distribution of hydrological conditions that are very similar to the hydrological distribution of the 21 traces. In addition, the mean of the representative trace is approximately equal to the mean of all 21 traces. Furthermore, the AURORA model run will only use the moderate sediment trace, which was estimated to have a 63.1% chance of occurring. Using a single sediment trace greatly expedites model runs by reducing the number of cases to be examined.

- This analysis uses the GTMax-Lite model to simulate the hourly operation of Glen Canyon Dam and the remaining hydropower facilities that comprise both the CRSP and Fontenelle powerplant. This model was designed specifically for the LTEMP EIS and consists of two configurations. One configuration models only the operation of Glen Canyon Dam, and the other configuration models the remaining aforementioned facilities. This is a simplification for power production because WAPA schedules and Reclamation dispatches all of the CRSP power units concurrently and incorporate some operating goals and guides that are not represented by GTMax-Lite.

- The methodology assumes that the electrical utilities being modeled engage in unfettered exchange with perfect information about the entire system when it comes to exchanging electrical energy and sharing capacity. In reality, each utility makes its own autonomous decisions with imperfect knowledge about both the future and the actions of competing utilities. Transmission constraints are also not explicitly modeled; neither are institutional nor regulatory obstacles to trade.

Figure 4.13-1 shows the modeling sequence and data flows for the power systems analysis. The following section briefly describes the methodology; a more detailed discussion of the methodology can be found in Appendix K, Sections K.1.4 and K.1.5.

Another noteworthy assumption is that "emergency exception criteria" as stipulated under the 1996 Record of Decision will continue under all LTEMP alternatives. Therefore, in accordance with the criteria, Glen Canyon Dam will be allowed to operate outside of minimum and maximum flow limits, daily change constraints, and both maximum hourly up- and down-ramp rates in the event of a power system emergency (e.g., grid energy imbalance events).

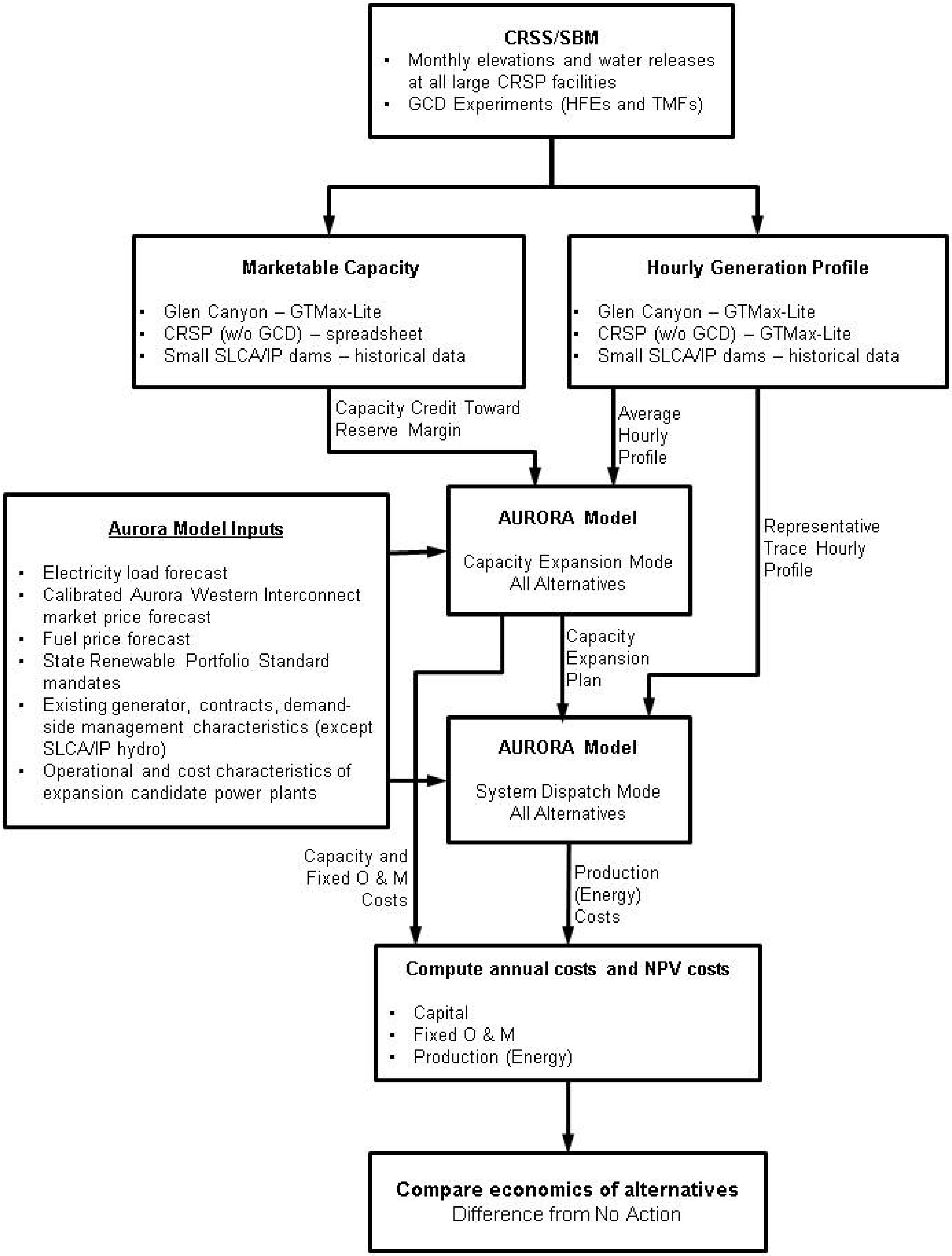

FIGURE 4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS

Alternative-specific Glen Canyon Dam operating criteria would affect the timing and amount of powerplant additions in the SLCA/IP system and system operation. Both would result in economic impacts that are measured by the AURORA model—the core tool used for power systems analysis. If the operating criteria under each alternative result in a reduction in the maximum output from Glen Canyon Dam during the time of peak system load, new generating capacity would be needed elsewhere in the SLCA/IP system to meet SLCA/IP peak loads. Alternative operating criteria could also change the timing of Glen Canyon Dam generation on both a monthly and hourly basis (i.e., less power generated in the high price peak periods and more generated in the low price off-peak hours). Such a change in hydropower operation may cause other powerplants, typically fossil-fuel thermal units, to increase expensive generation in peak hours and decrease relatively inexpensive generation in off-peak hours. The differences in the timing of new resources and in the way the system is dispatched mean that the cost of serving SLCA/IP loads over the 20-year LTEMP period would differ from system operations under the existing operating criteria. Therefore, for each alternative, AURORA was used for two major purposes: (1) to determine the capacity expansion pathway over time during the study period for a joint WAPA/LTF customer system; and (2) to perform a least-cost unit commitment and system dispatch for a given expansion pathway using a single representative hydrology future or trace.

Considerable amounts of data were needed for the AURORA model runs, including:

- Hourly electricity load forecasts for all WAPA’s LTF customer utilities

- Western Interconnection electricity market price forecasts (spot market prices were projected using a configuration of AURORA representing the entire Western Interconnection and a spreadsheet model that calibrated those prices to historical 2013 observations at the Palo Verde market hub, which is a key Western Interconnection marketing hub often used as driver for SLCA/IP operations)

- Fuel price projections

- Renewable resource targets; from state renewable portfolio standards and/or from utility-specific goals as stated in their integrated resource plans (IRPs)

- Characteristics of contracts that customer utilities have with other utilities and with other WAPA offices other than SLCA/IP

- Characteristics of demand-side management programs

- Operational and cost characteristics of powerplants owned by customer utilities

- Operational and cost characteristics of candidate generating unit technologies for capacity expansion to reliably meet future SLCA/IP system loads

More details on data sources and how data was generated can be found in Appendix K, Sections K.1.6.1 and K.1.6.3.

Although the AURORA model has its own database of powerplant characteristics, fuel price projections, and hourly load profiles for a number of areas within the entire Western Interconnection, these data were compared to publicly available data sources to verify data accuracy and consistency. Such data sources include those available from the Energy Information Administration (EIA), as well as IRPs that WAPA's customers provide WAPA or post on their company website. Since the methodology modeled WAPA's eight large customers in detail, it was necessary to carefully examine the powerplant characteristics in the AURORA inventory and benchmark them against data compiled by EIA and in IRPs.

Due to the complexities of SLCA/IP hydropower operating criteria and mandates unrelated to power production, AURORA could not model the dispatch of these resources at a level of detail that is required for this study. Therefore, the GTMax-Lite model and other spreadsheet models were used to project powerplant-specific hourly production levels over the study period. The results of these models were input to AURORA as a time series of fixed hourly energy injections into the power grid. Input data for GTMax-lite and the spreadsheet models for each alternative came from the CRSS model and SBM models that include monthly reservoir elevations and water release volumes, as well as the type and timing of experiments at Glen Canyon Dam. Other inputs include both scheduled maintenance outages and forced outages at Glen Canyon Dam and the other large SLCA/IP facilities. Since alternatives only targeted the operation of Glen Canyon Dam, the generation at all other SLCA/IP was typically the same in every alternative. However, in some situations, when Glen Canyon Dam could not provide spinning reserves and/or regulation services, a portion or all of these grid services were provided by powerplants in the Aspinall Cascade, affecting the operations of these facilities.

SLCA/IP firm capacity was an input to the AURORA expansion model. It represents the amount of hydroelectric capacity WAPA is obligated to provide to LTF customers regardless of the state or condition of SLCA/IP resources. It is also the amount of capacity credited toward meeting the SLCA/IP system reserve margin; that is, the spare capacity above the annual coincidental peak of the electric power system. For this study, the reserve margin was assumed to be 15%, which is a typical value in the Western Interconnection. Because WAPA markets the capacity and energy produced by all 11 SLCA/IP facilities as a package, firm capacity was determined for the entire facility group. The GTMax-Lite model results were used to compute the capacity contribution from Glen Canyon Dam, while a spreadsheet using CRSS and SBM results were used to compute the contribution from the other large CRSP facilities. Historical data were used to compute firm capacity from the small SLCA/IP facilities; namely, Deer Creek, Elephant Butte, Towaoc, McPhee, and Molina. Because alternatives only affected Glen Canyon Dam's operation under almost all circumstances, only the contribution of Glen Canyon Dam to firm capacity varied by alternative.

This LTEMP analysis used an exceedance level of 90% to determine firm capacity; that is, 90% of the time that amount of capacity or more is available from SLCA/IP facilities at the time of system peak load. This exceedance level was selected based on a retrospective study performed by Argonne. It shows that the level of SLCA/IP capacity marketed and offered by

WAPA to its FES customers over the last 10 years is approximately at a 90% exceedance level. That is, WAPA has enough SLCA/IP capacity to meet its obligation 90% of the time. Firm capacity at 50% and 99% exceedance levels were also modeled. These results are presented in this section and detailed in Appendix K, Section K.1.10.4.

Hourly generation profiles from all SLCA/IP facilities were an input to both the AURORA expansion and dispatch models. The hourly profile based on the average of all 21 hydrology traces is input to the expansion model, and the hourly profile based on the representative trace is input to the dispatch model. The appropriate configuration of GTMax-Lite is used to compute the hourly generation profiles for Glen Canyon Dam and for the other large CRSP facilities.

The results from the AURORA model run in expansion mode show capacity expansion plans for each alternative over the study period. The plans specify the type of technology built (such as combustion turbines, combined cycle plants, coal plants, nuclear powerplants, etc.), the capacity of the unit, and the year it begins operating. A post-processor spreadsheet written by Argonne computed the annual capacity investment and fixed O&M costs for the new units over the study period. The AURORA model was given a wide selection of technologies from which to choose future capacity additions, including conventional and advanced natural gas combustion turbines, conventional and advanced gas/oil combined cycle units, scrubbed and pulverized coal units, integrated gasification combined cycle units, nuclear units, wind turbines, and solar thermal and photovoltaic facilities. More details on expansion technology candidates and their cost and performance characteristics are provided in Appendix K, Section K.1.6.3.

The capacity expansion plan for each alternative was an input to the AURORA run in dispatch mode to simulate the operation of the system for every hour in the entire study period for a single hydrological future or trace, which is known as the representative trace. Because the dispatch was run for only a single hydrological trace, selection of the trace is very important. Trace 14 was selected as the representative trace. More detail on the method used to select the representative trace can be found in Appendix K, Attachment K.3.

Results of the AURORA dispatch model consisted of costs to produce the electrical energy to meet the system load demand. Production costs are the sum of powerplant fuel costs, variable O&M costs, unit start-up costs, and cost of power purchased from the spot market. Spot sales are subtracted from total system costs. Results from the AURORA expansion and dispatch models (namely, capital, fixed O&M, and production or energy costs) were combined to determine the total annual costs for each alternative over the study period. The net present value stream of annual costs was also calculated to facilitate comparison of each alternative to Alternative A. This single lump-sum value was based on a discount rate of 3.375%, a rate that is used by Reclamation for cost-benefit studies of projects.

Sensitivity analyses were performed to determine the effect of several power systems model assumptions on the estimated cost of LTEMP alternatives. These sensitivity analyses evaluated the effect of differing assumptions for exceedance values (50, 90, and 99%), discount rates (1.4 vs. 3.375%), expansion pathways (various combinations of new combustion turbines and combined cycle plants), hydrology (representative 20-year trace vs. average of 21, 20-year traces), and ancillary services (increasing [103 to 160 MW] vs. stable [67 MW] ancillary service provision). These analyses indicated that the cost alternatives may be either lower or higher for changes in grid operations and/or capacity replacement than those for the baseline assumption set. The analyses also demonstrated that results are more sensitive to some model assumptions than others. An overview of results is presented in Section 4.13.2.3; details are presented in Appendix K (Sections K.1.10.4 through K.1.10.9).

4.13.1.2 Wholesale Rate Impacts

The economic impact of changed operations at the Glen Canyon Dam Powerplant on electrical power production and value is the impact—measured in dollars—on the economy. It includes the system cost of changing the value of electrical power produced at Glen Canyon Dam as a result of changing the timing and routing of water releases (i.e., turbine and bypass). It also includes the expense of constructing (or savings resulting from forgoing construction of) additional electrical generators because of changes in firm SLCA/IP hydropower capacity. Wholesale rates[28] impacts describe how these economic impacts are distributed to utilities that purchase Glen Canyon Dam electrical power from WAPA at the SLCA/IP rate. The change in SLCA/IP rate among alternatives reflects the economic costs of altered Glen Canyon Dam operations.

WAPA sets rates as low as possible consistent with sound business principles to repay the federal government’s investment in generation and transmission facilities in addition to specific non-power costs that power users are legislatively required by Congress to repay, such as irrigation costs that are beyond the irrigators’ ability to repay. Sales of federal electric power and transmission repay all costs (including interest) associated with generating and delivering the power. WAPA prepares a power repayment study (PRS) for each specific power project to ensure the rates are sufficient to recover expenses.

It was assumed that WAPA will adjust its FES rates as necessary to address costs associated with LTEMP operations, including all net purchased energy, federal capital costs, fixed O&M costs, and interest expense. Interest expense is calculated by multiplying each investment’s prior year unpaid balance by the appropriate interest rate. Computations of total purchase energy for each alternative are based on projections of total hourly generation from all SLCA/IP hydropower resources and hourly FES customer loads. The difference between hourly generation and load is resolved by hourly non-firm energy transactions at an energy price projected by the power systems economic analysis described in Section 4.13.1.1. All capital costs and fixed O&M costs associated with a reduction in Glen Canyon Dam Powerplant capacity are also paid by WAPA and passed on to its customers via adjustments to FES wholesale rates. See Appendix K, Section K.2, for more detailed information on the PRS and wholesale rate modeling process.

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[28] The term “rate” is used rather than “price.” This is the standard convention for wholesale electrical commodities. Rate is the price charged for an energy unit, whether capacity or energy. Rate is often used to describe wholesale prices because it is the price of wholesale units and not necessarily the units used for retail sales.

Several calculations were performed to determine the impact of the LTEMP EIS alternatives on the SLCA/IP rate. Three rates were calculated for each of the seven alternatives: (1) a firm energy rate, (2) a firm capacity rate, and (3) a composite rate. The SLCA/IP FES rate is the price paid per unit of product sold by WAPA's CRSP Management Center to its SLCA/IP FES customers. These calculations and analyses were performed by WAPA CRSP Management Center staff.

WAPA markets SLCA/IP electrical power under firm, long-term contracts. Under these contracts, WAPA is required to deliver this electrical power to federal points of delivery regardless of hydrological conditions, status of generating units, or changes in the operational criteria of the SLCA/IP hydropower plants. The current FES marketing contracts expire on September 30, 2024. For the period following 2024, WAPA is currently engaged in developing a marketing plan. This requires a formal public process in compliance will applicable federal law.

Several assumptions had to be made in order to estimate LTEMP impacts. First, it was assumed that WAPA will continue with its current SLCA/IP obligations until the current marketing period ends and the existing contracts expire.[29] This requires that WAPA deliver the same amount of electrical power and energy to SLCA/IP customers until the end of fiscal year (FY) 2024, regardless of the alternative analyzed. Recognizing uncertainties about WAPA's future marketing of SLCA/IP resources between 2025 and 2034, net firming expenses for the post-2024 time period were analyzed under two sets of assumptions. These are as follows:

1. A continuation of existing SLCA/IP FES contract commitments between FY 2025 and FY 2034 (referred to as No Change or "NC" in Section 4.13.2.4); and

2. A reduction in SLCA/IP FES contract commitments so that net firming expenses are equal to $0 between FY 2025 and FY 2034. This means, for the numbers included in the SLCA/IP power repayment study, zero dollars of firming expense and zero additional dollars of revenue from market sale or from available hydropower sales (referred to as Resource Available or "RA" in Section 4.13.2.4).

These two assumptions constitute "bookends" regarding the outcomes possible in the development of the post-2024 marketing plan.[30] These bookends are for modeling purposes only. They represent a very broad range of possible FES obligations of electrical power in the post-2024 marketing period. The bookends will almost certainly encompass the actual rate impact, once the post-2024 marketing plan is completed. It should be noted that the

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[29] There is a provision in the existing SLCA/IP contracts to modify the FES obligations upon a 5-year notice to SLCA/IP customers. However, considering the probable timing of new operating criteria for the Glen Canyon Dam following the completion of the LTEMP EIS and the issuance of a ROD, a 5-year notice would not be significantly different than the end of the current marketing period.

[30] Western could choose a post-2024 SLCA/IP FES obligation of electric power that exceeds its current obligation. However, prior to completion of the required public process it would be difficult to determine what the higher obligation would be that could be considered a reasonable bookend.

establishment of these bookends is not an attempt to predict or to anticipate WAPA's choice prior to the conclusion of the required public process.

4.13.1.3 Retail Rate Impacts

WAPA markets power to utilities serving approximately 5.8 million retail customers in Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming (Reclamation 2012d). Customers include small and medium-sized towns that operate publicly owned electrical systems, irrigation cooperatives, and water conservation districts; rural electrical associations or generation and transmission cooperatives who are wholesalers to these associations; federal facilities such as Air Force bases, universities, and other state agencies; and American Indian Tribes.

The effect of reductions in available generating capacity at Glen Canyon Dam under each of the alternatives on retail electricity rates and bills for customers of municipal, cooperative, and other entities receiving power from WAPA was estimated in four steps. First, a detailed database of retail revenues and sales was developed for 226 utility systems that directly or indirectly receive an allocation of SLCA/IP preference power including American Indian Tribes. This database was combined with aggregate production costs (variable O&M costs, purchased power, and fuel expenses), capital investments for capacity additions, and fixed O&M costs derived from the AURORA analysis. Second, capacity additions were converted to revenue requirements using a carrying charge analysis (see Appendix K, Section K.3.1) along with the capital cost of different investments. Third, the cost of changing Glen Canyon Dam operations under each alternative was distributed to each retail utility system by simulating the WAPA SLCA/IP capacity and energy allocation process. Fourth, overall rate impacts to individual utility systems (including Tribal Systems) were allocated to residential and non-residential consumers to compute retail rate and bill impacts. The process of using a carrying charge analysis along with aggregate production costs does not require SLCA/IP wholesale rates. This methodology, which uses production costs and carrying charges, results in somewhat higher rate impacts than one that uses SLCA/IP wholesale rates.

The objective of the retail rate impact analysis is to measure the change in electric bills that consumers who use electricity in their homes or businesses will ultimately incur because of changes in the way Glen Canyon Dam operates. Retail rate impacts can be measured directly from the change in capacity and energy costs that are computed in the power systems analysis along with the utility carrying charges. This direct method of computing retail rate impacts involves allocating changes in energy and capacity cost to distribution systems and then dividing the cost changes by retail revenues. All of the economic impacts come from the capacity cost (including fixed O&M) and energy cost changes (including ancillary service values). Using this method, additional evaluation of WAPA wholesale rates was unnecessary to derive retail rate impacts, and the wholesale rate analysis presented in Section K.2 of Appendix K was not used as the basis of the retail rate analysis presented here. The power systems simulations combined with the carrying charge rate analysis applied to new capacity resulting from Glen Canyon Dam operation changes measures impacts on wholesale power cost that must ultimately be attributed directly to retail ratepayers. Appendix K demonstrates that the methodology that computes retail rates using a multi-step process with economic capacity and energy costs results in an appropriate estimate of retail rate impacts.

While the process of computing retail rate impacts from the capacity and energy cost changes implies changes in capacity allocation, under current contract provisions with customer utilities, WAPA may maintain the same capacity allocation to each customer entity. Given this contractual obligation, WAPA rather than the individual utilities may have to replace the lost capacity at Glen Canyon Dam by purchasing the shortfall from other sources. Eventually, these increased costs would be passed on to entities who are allocated preference power and rates would have to be increased because of higher capacity and energy cost. This process of assuming that WAPA would pay for the capacity and energy costs associated with changes in Glen Canyon Dam operations results in the same retail rate impacts as the assumption that the wholesale cost impacts are simply paid by the utilities themselves as long as WAPA would pass on the costs as they are incurred. If WAPA would defer the cost increases, the changes in energy and capacity costs would still be paid, but with a temporary deferral that would presumably include financing costs. Attempting to incorporate potential deferral strategies in WAPA's wholesale rate policy is neither appropriate nor practical in assessing retail rate impacts. For example, if capacity costs and production costs increase, but WAPA incurs the cost for a period of years but then later increases the rate including cost of capital, it would not be appropriate to include the deferral in the rate impacts. Finally, in order to provide a relative benchmark indication of the effects of Glen Canyon Dam capacity cost changes on costs incurred to purchase power, the average aggregate capacity and energy costs are measured relative to amount of money that WAPA currently collects from capacity and energy allocations (see Appendix K for details).

4.13.1.4 Hoover Dam Impacts

Hoover Dam is located about 370 mi downstream of Glen Canyon Dam. Its powerhouse has 17 turbines that have a combined hydropower nameplate capacity of approximately 2,074 MW. Hoover Dam operating criteria are unaffected by LTEMP EIS alternatives. Its energy production and economic value, however, will be impacted primarily by temporary changes in Lake Mead elevation that are projected to occur within a water year. In addition, alternatives will occasionally result in reallocation of Lake Mead monthly water release volumes within a year, when changes in projected December end-of-month Lake Mead elevations result in a different operating condition. Alternatives B, D, and E have the same Glen Canyon Dam October through December total release volumes as Alternative A, and therefore do not affect the Lake Mead operating condition and thus release volumes from Hoover Dam.

Changes in Lake Powell monthly water releases among LTEMP alternatives will affect pool elevations in Lake Mead, and these in turn will affect the Hoover Dam Powerplant derated capacity and energy generation. A modeling tool of Hoover Powerplant monthly operations was developed for the LTEMP EIS to estimate these impacts on Hoover Powerplant economics. The tool, referred to here as the Hoover Powerplant Model, computes and compares two economic metrics; namely, energy and firm capacity that could be used as a capacity credit in utility integrated resource plans. Both are measured in terms of NPV for each alternative.

To perform the analysis, projections of monthly water releases from Hoover Dam were obtained from CRSS, and Lake Mead end-of-month elevation projections were obtained from the SBM for all 21 hydrology traces for each alternative over the study period. Using information from Reclamation, algorithms were developed that relate reservoir elevation and reservoir storage to water-to-power conversion efficiencies and derated powerplant capacity. The Hoover Powerplant Model used this information to determine the difference in monthly generation between Alternative A and each of the other alternatives for all 21 hydrology traces. The Western Interconnection electricity market price forecasts, which are identical to the prices used in the Aurora model simulation of the SLCA/IP system, were used in the Hoover Powerplant Model to compute the value of the generation from the Hoover Powerplant. The value of monthly generation was computed by multiplying the monthly energy generation by the market price of electricity, accounting for the difference in price between energy generated in peak hours versus off-peak hours. Based on information from Reclamation, it was assumed that 95% of generation at the Hoover Powerplant takes place in peak hours and only 5% in off-peak hours. There were no projected changes in firm capacity.

The Hoover Powerplant Model uses methods that are simpler than the ones used to measure the economic impacts of the SLCA/IP system, and it uses a monthly rather than hourly time resolution. In addition, many of the assumptions that drive model results are uncertain. More details on the modeling methodology and the results are presented in Appendix K, Section K.5.

4.13.2 Summary of Hydropower Impacts

This section and Table 4.13-1 summarize the potential impacts of alternative operating criteria on Glen Canyon Dam's hydropower resources. These impacts are measured in terms of changes in both powerplant capacity and generation and associated economic value. Impacts are analyzed from an overall systems perspective in which least-cost electricity production costs are computed and regional power system capacity expansion pathways are determined. This section also discusses how changes in system resources and operations, caused by operational changes at Glen Canyon Dam, impact the wholesale rate that WAPA charges it FES customers and the retail electricity rate that FES customers charge to their end-use customers. Table 4.13-1 does not include the rate impacts on American Indian Tribes; they are discussed separately in Appendix K, Section K.3.

4.13.2.1 Monthly Water Release Impacts

Differences among LTEMP alternatives do not occur from annual water release volumes, but rather from the routing and timing of these water releases during monthly, daily, and hourly timeframes. The total volume of water released from Glen Canyon Dam over the 20-year LTEMP period is essentially identical under all LTEMP alternatives. Also, differences among alternatives in annual water release volumes are less than 1%. However, alternatives significantly impact the timing of water releases within a year. For example, as compared to Alternative A, Alternative F releases much higher water volumes during March, April, May, and June and much

TABLE 4.13-1 Summary of Impacts of LTEMP Alternatives on Hydropower Resources[a]

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Overall summary of impacts resulting from changes in operations at Glen Canyon Dam	No change from current condition; second highest firm capacity and sixth-lowest total cost to meet electric demand over the 20-year LTEMP period; no change in average electric retail rate or average monthly residential electricity bill.	Compared to Alternative A, 0.3% decrease in average daily generation (MWh) and 3.8% increase in firm capacity (MW); 0.02% decrease in the cost of generation, 0.45% decrease in the cost of capacity, and 0.04% decrease in total cost to meet electric demand over the 20-year LTEMP period; small decreases in the average electric retail rate (–0.27%) and the average monthly residential electricity bill (–$0.27) in the year of maximum rate impact.	Compared to Alternative A, 0.8% decrease in average daily generation (MWh) and 17.5% decrease in firm capacity (MW); 0.08% increase in the cost of generation, 6.09% increase in the cost of capacity, and 0.41% increase in total cost to meet electric demand over the 20-year LTEMP period; small increase in average retail electric rate (0.43%) and average monthly residential electricity bill ($0.40) in the year of maximum rate impact.	Compared to Alternative A, 1.1% decrease in average daily generation (MWh) and 6.7% decrease in firm capacity (MW); 0.12% increase in the cost of generation, 3.12% increase in the cost of capacity, and 0.29% increase in total cost to meet electric demand over the 20-year LTEMP period; small increase in average retail electric rate (0.39%) and average monthly residential electricity bill ($0.38) in the year of maximum rate impact.	Compared to Alternative A, 0.7% decrease in average daily generation (MWh) and 12.2% decrease in firm capacity (MW); 0.06% increase in the cost of generation, 3.52% increase in the cost of capacity, and 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period; small increase in average retail electric rate (0.50%) and average monthly residential electricity bill ($0.47) in the year of maximum rate impact.	Compared to Alternative A, 1.9% decrease in average daily generation (MWh) and 42.6% decrease in firm capacity (MW) (lowest of alternatives) ; 0.42% increase in the cost of generation, 4.03% increase in the cost of capacity, and 1.17% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period; highest change in average retail electric rate (1.21%) and average monthly residential electricity bill ($1.02) in the year of maximum rate impact.	Compared to Alternative A, 1.7% decrease in average daily generation (MWh) and 24.2% decrease in firm capacity (MW); 0.34% increase in the cost of generation, 7.39% increase in the cost of capacity, and 0.73% increase in total cost to meet electric demand over 20-year LTEMP period; small increase in average retail electric rate (0.64%) and average monthly residential electricity bill ($0.59) in the year of maximum rate impact.

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Overall summary of Hoover Dam economic impacts	No change in the value of generation.	No change in the value of generation.	2.0% increase in the value of generation.	1.0% increase in the value of generation.	1.2% increase in the value of generation.	4.1% increase in the value of generation.	1.4% increase in the value of generation.
Impacts on Generation and Capacity at Glen Canyon Dam							
Annual average daily generation (MWh)[e]	11,599 (no change from current condition)	11,567 (0.3% decrease)	11,506 (0.8% decrease)	11,477 (1.1% decrease)	11,521 0.7% decrease	11,379 (1.9% decrease)	11,403 (1.7% decrease)
SLCA/IP firm capacity (MW)[f]	737.2 (no change from current condition)	765.3 (3.8% increase)	608.1 (17.5% decrease)	687.6 (6.7% decrease)	647.0 (12.2% decrease)	423.1 (42.6% decrease)	558.2 (24.2% decrease)
SLCA/IP replacement capacity (MW)[g]	Not applicable	–28.1	129.1	49.6[a]	90.2	314.1	179.0
Impacts on Generation and Capacity at Glen Canyon Dam (Cont.)							
System-level generating capacity additions (MW)[h]	4,820 (no change from current condition)	4,820 (no change from current condition)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,280 (9.5% increase)	5,050 (4.8% increase)
Impacts on Power System Economics Resulting from Changes in Operations at Glen Canyon Dam							
NPV of SLCA/IP systemwide production cost ($million)[i]	34,228 (no change from current condition)	34,221 (0.02% decrease)	34,255 (0.08% increase)	34,270 (0.12% increase)	34,249 (0.06% increase)	34,373 (0.42% increase)	34,345 (0.34% increase)
NPV of SLCA/IP capital cost ($million) for capacity expansion[i]	1,643 (no change from current condition)	1,635 (0.49% decrease)	1,746 (6.27% increase)	1,696 (3.23% increase)	1,703 (3.65% increase)	1,882 (14.55% increase)	1,769 (7.67% increase)

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Impacts on Power System Economics Resulting from Changes in Operations at Glen Canyon Dam (Cont.)							
NPV of fixed O&M cost ($million) for capacity expansion[i]	345 (no change from current condition)	344 (0.29% decrease)	363 (5.22% increase)	354 (2.61% increase)	355 (2.90% increase)	385 (11.59% increase)	366 (6.09% increase)
NPV of all costs ($million)[i]	36,216 (no change from current condition)	36,200 (0.04% decrease)	36,364 (0.41% increase)	36,320 (0.29% increase)	36,307 (0.25% increase)	36,640 (1.17% increase)	36,480 (0.73% increase)
Difference in Total NPV ($million) Relative to No Action	Not applicable	–16	148	104	91	424	264
Local Hydropower Value ($million)[j]	2,662 (no change from current condition)	2,657 (0.2% decrease)	2,614 (1.8% decrease)	2,613 (1.8% decrease)	2,620 (1.6% decrease)	2,540 (4.6% decrease)	2,556 (4.0% decrease)
Impacts on Wholesale Rates Resulting from Changes in Operations at Glen Canyon Dam							
Energy ($/kWh)							
NC[k]	13.52	13.54	13.99	13.94	13.84	15.67	16.07
Ra[l]	13.40	13.22	14.55	13.78	14.01	16.86	15.22
Average	13.46	13.38	14.27	13.86	13.93	16.27	15.65
Capacity ($/kW)							
NC	5.74	5.75	5.94	5.92	5.88	6.66	6.83
RA	5.69	5.62	6.18	5.85	5.95	7.16	6.50
Average	5.72	5.69	6.06	5.89	5.92	6.91	6.67

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Impacts on Electric Retail Rate Payers Resulting from Changes in Operations at Glen Canyon Dam							
Percent change in retail rates (maximum impact year)[m]	No change from current conditions	–0.27%	0.43%	0.39%	0.50%	1.21%	0.64%
Change in monthly residential bill (maximum impact year)[n]	No change from current conditions	–$0.27	$0.40	$0.38	$0.47	$1.02	$0.59
Impacts on Hoover Dam Power Systems Economics Resulting from Changes in Operations at Glen Canyon Dam							
Total NPV of generation ($million)[o]	2,362.3	2,362.3	2,408.6	2,384.2	2,390.2	2,451.1	2,392.0
Change in NPV of generation ($million)	No change from current conditions	No change from current conditions	46.4 (2.0% increase)	21.9 (1.0% increase)	27.9 (1.2% increase)	88.8 (4.1% increase)	29.7 (1.4% increase)

[a] Assumptions employed in models used to estimate impacts in this table were based on best available information. Sensitivity analyses were performed to determine the possible effect of these assumptions on the estimated cost of LTEMP alternatives. These analyses indicated that costs of alternatives could vary based on particular assumptions made. The analyses also illustrated that results are more sensitive to some model assumptions than others. An overview of results is presented in Section 4.13.2.3; details are presented in Appendix K (Sections K.1.10.4 through K.1.10.9).

[b] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative C compared to Alternative A, estimated at $148 million, by about $24.5 million, resulting in a total cost difference of about $173 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.41% increase in cost to a 0.48% increase in cost. The relative ranking of Alternative C compared to other alternatives would not change as a result of adding the cost of experimental low summer flows.

Footnotes continued on next page.

TABLE 4.13-1 (Cont.)

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[c] The results presented here are based on the modeling conducted prior to making several adjustments to Alternative D, and they do not include the cost of experimental low summer flows. As presented in Section 4.13.3.4, experimental low summer flows would increase costs by $15 million, while the adjustments would reduce costs by $58.9 million. Combined, the cumulative effect of these adjustments may reduce the relative cost of Alternative D compared to Alternative A, estimated at $104 million, by approximately $44 million over a 20-year period; the resulting difference from Alternative A would be $60 million. These adjustments reduce the percent difference relative to Alternative A from a 0.29% increase in cost to a 0.17% increase in cost. These adjustments would also result in slight reductions to the retail rate costs. The relative ranking of Alternative D compared to other alternatives would change from fourth to third lowest cost.

[d] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative E compared to Alternative A, estimated at $91 million, by about $9.95 million, resulting in a total cost difference of about $101 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.25% increase in cost to a 0.28% increase in cost. The relative ranking of Alternative E compared to other alternatives would change from third to fourth lowest cost.

[e] Average daily Glen Canyon Dam generation under representative hydrological conditions.

[f] Firm capacity is calculated based on all 21 hydrology traces with median sediment input (sediment trace 2), which has the highest likelihood of occurrence. It is calculated at the 90% exceedance level, which means that at least that amount of SLCA/IP federal hydropower plant capacity is available in the peak month of August 90% of the time.

[g] Replacement capacity is the difference between the firm capacity in Alternative A and the firm capacity of another alternative; it represents the capacity that would need to be replaced somewhere in the power system if that alternative was implemented.

[h] Additional generation capacity required under the LTEMP alternatives for WAPA’s customers over the 20-year LTEMP period to not only meet future load demand but also account for loss/gain in capacity at Glen Canyon Dam due to the alternative operating constraints.

[i] Net present value ($million 2015) of costs to meet total system electric demand over 20-year study period for all SLCA/IP customers under representative trace. Discount rate is 3.375%.

[j] Net present value of electricity generated at Glen Canyon Dam over the 20-year LTEMP period ($million 2015).

[k] NC = no change from current LTF commitment levels.

[l] RA = “resource available” (i.e., commitment level would equal available SLCA/IP federal hydropower resource).

[m] The unweighted average percent changes in retail rates relative to Alternative A across all systems with available data for the year with the highest percentage impact.

[n] The average change in residential electric bills (2015 dollars) relative to average residential bills in Alternative A for the year with the maximum rate impact (residential bills are not weighted by utility size).

[o] Net present value of electricity generated at Hoover Dam over the 20-year LTEMP period ($million 2015).

lower water volumes during July and August. Alternatives also impact the daily profile of water releases. Changes in operating criteria such as maximum and minimum release restrictions and mandates that limit water release changes over time result in very different release patterns during most days. For example, Alternative F requires water releases from Glen Canyon Dam to be at a constant rate an entire day. In contrast, Alternative A allows powerplant operators to change water release levels during a day such that power production more closely matches FES customer energy requests and/or in response to the market price of electricity.

Lastly, alternatives affect the routing of water releases from the dam. Water is typically released through one or more of the powerplant's eight turbines to produce electricity. However, dependent on the pressure exerted by the water elevation in Lake Powell, turbines have a limited amount of water that can flow through them during an hour. In addition, the generating capacity of a unit and the operational status (e.g,, online or out-of-service) limits the flow of water through it. Therefore, whenever a water release is required to exceed the combined flow capabilities of the generating units that are in operation (i.e., emergency, spill avoidance, and approved experiments), some of the water is released through bypass tubes and spillways. Releases such as this that produce no energy are referred to as non-power releases. Each alternative has a unique set of HFE specifications that affect the frequency and duration of Glen Canyon Dam non-power water releases.

Non-power releases can also occur under very low (i.e., dry) hydropower conditions when the Lake Powell elevation is below a minimum turbine water intake level (minimum power pool). All of the water is released through bypass tubes and, therefore, no electricity is produced until the water level rises above the minimum power pool level. All non-power water releases are considered an irretrievable loss of hydropower generation.

4.13.2.2 Hydropower Power Generation and Capacity Impacts

Table 4.13-1 summarizes the impacts of changes in Glen Canyon Dam operations under each alternative on hydropower generation and capacity. Under Alternative A, the average daily generation at Glen Canyon Dam over the 20-year study period is projected to be 11,599 MWh under representative conditions; that is, the monthly water releases and generation levels expected under one of the 21 analyzed hydrology traces, trace 14, which was considered representative of the full range of annual inflow volumes over the 20-year LTEMP period. On average, this represents 72.8% of the generation produced by all SLCA/IP hydropower resources over the 20-year LTEMP study period. With the remaining alternatives, generation would vary between 11,567 MWh under Alternative B (a reduction of 0.3% compared to Alternative A) to 11,379 MWh under Alternative F (a reduction of 1.9%) under representative conditions (Table 4.13-1). These relatively small differences (i.e., less than 2%) in average daily generation among the alternatives are not due to the amount of water released from the dam, but largely attributed to differences in the amount of water routed through bypass tubes to conduct HFEs, which, as described in the previous section, does not generate electricity and requires replacement resources. In addition, differences in monthly reservoir elevations affect both water-to-power conversion efficiency and bypass releases when reservoir elevation is below minimum power level.

Although there is little difference in annual average daily generation at Glen Canyon Dam among the alternatives, there are monthly differences. Under representative hydrological conditions, average daily generation under Alternative A ranges from 8,640 MWh in March to 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to 11,511 MWh in January (Figure 4.13-2). Although generation under Alternative B would be similar to Alternative A between June and August, slightly less electricity would be generated during January through May, and during October through December. In contrast with Alternatives A and B, all other alternatives (except for Alternative F, which is discussed later) have less average daily generation in the summer months of June, July, and August when electricity demand is at its peak. Alternatives C, D, E, and G have a higher average daily generation in the spring months of March, April, and May than Alternatives A and B, with Alternative C generally having the highest values. Alternatives D, E, and G have higher average daily generation in the fall months of October and November compared to Alternatives A and B. However, in September, October, and November, Alternative C has a considerably lower average daily generation than almost any other alternative. In the winter months of December, January, and February, Alternatives A and B typically have a higher average daily generation than most other alternatives.

Generation under Alternative F would result in the most deviation from Alternative A, with a shifting of annual peak generation from the mid-summer months to late spring/early summer, producing a maximum of 19,995 MWh in June, significantly higher than the peak output under Alternative A (Figure 4.13-2). By contrast, generation during the summer would fall considerably, to a low of 9,708 MWh in July, exceeding 9,000 MWh in August, September, and November and falling to just over 6,900 MWh in December and January.

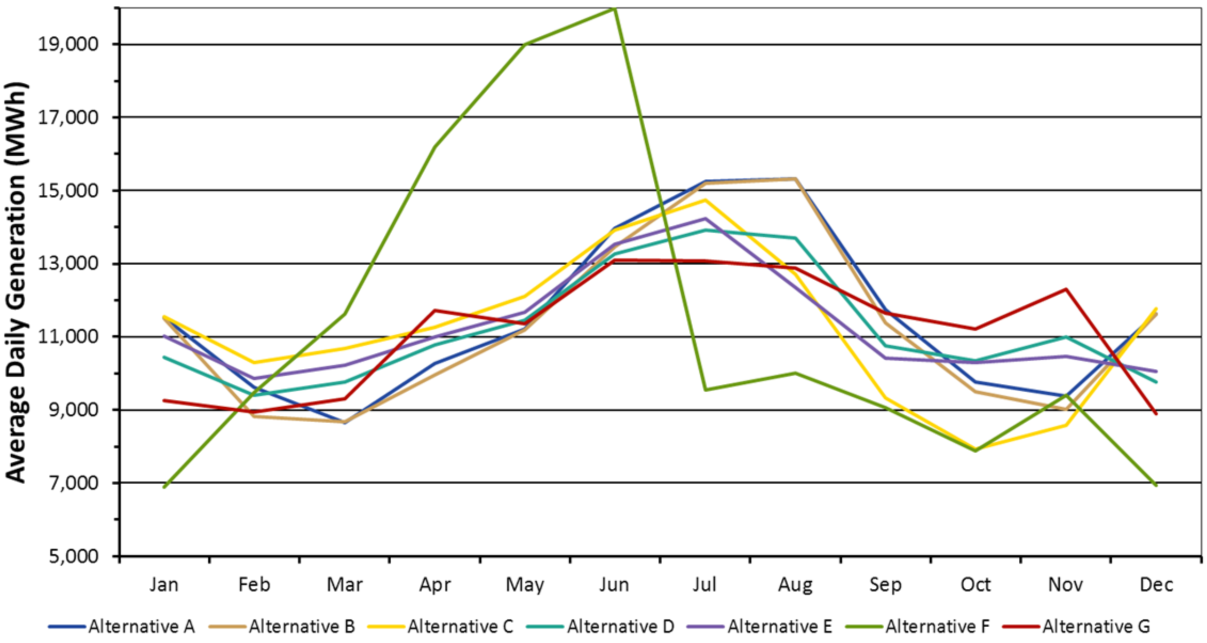

FIGURE 4.13-2 Average Daily Glen Canyon Dam Generation under Representative Hydrological Conditions under LTEMP Alternatives

Although the Glen Canyon powerplant is rated at 1,320 MW, it has been operationally restricted since 1996 and is rarely allowed to produce power at this capacity level (Veselka et al. 2010). This is due to several factors such as the number of units that are operable, the reservoir elevation, grid reliability considerations, and reservoir operating criteria. The latter is most important for the purposes of estimating economics under different LTEMP alternatives. However, it can produce at rated capacity during extremely high hydropower conditions and during high peak release HFEs when the reservoir is relatively high (i.e., about 33,000 cfs and higher).

As shown in Table 4.13-1, under Alternative A, there would be about 737 MW of firm capacity available from the entire SLCA/IP to meet peak system loads. This capacity is based on the assumption that 90% of the time this amount of capacity or more would be available when the system peak loads occur. Under Alternatives C, D, E, F, and G, the firm capacity would decrease to between 687.6 MW under Alternative D to 423.1 MW under Alternative F.

Except for Alternative B, under which the capacity is 28.1 MW higher than Alternative A, all other alternatives would provide approximately 50 MW to 314 MW less capacity—that is, a reduction that ranges from of 6.7% to 42.6% compared to Alternative A. Capacity differences mainly stem from the level of Glen Canyon Dam operational flexibility (daily change, ramp rates, etc.) and monthly water release volumes that are allowed under each alternative in conjunction with both reservoir elevations and monthly water release levels. Operations under Alternative B allow the highest level of flexibility, while Alternatives F and G, which require steady flows each day, restrict capacity. This lost capacity would need to be replaced somewhere in the SLCA/IP system or purchased from an entity outside of the SLCA/IP system footprint.

For LTEMP, it is assumed that the SLCA/IP system will build Glen Canyon Dam replacement capacity. SLCA/IP firm capacity affects the amount and timing of generating units that will be constructed in the future to reliably meet forecasted increases in electricity demand in the service territories of WAPA's FES customer utilities and to replace the retirement of existing powerplant generating capacity. Under Alternative A, an estimated 4,820 MW of new capacity would be built by WAPA's customer utilities. System capacity expansion additions are phased in over time such that a minimum 15% capacity reserve margin is attained in each year of the 20-year LTEMP period. Under alternatives with less SLCA/IP firm capacity, more new generating capacity must be built and system capacity expansion would need to begin sooner. Under Alternative B, 4,820 MW of new capacity would also be added by the end of the LTEMP period; however, because Alternative B has slightly more firm capacity available, one new generating unit would need to be constructed a year later than under Alternative A. All other alternatives have less firm capacity than Alternative A. Under Alternatives C, D, E, and G, 5,050 MW of new capacity would be required (an increase of 230 MW, or 4.8%, compared to Alternative A), and under Alternative F, 5,280 MW of new capacity would be required (an increase of 460 MW, or 9.5%) (Table 4.13-1). Also note that because the capacity is built in sizes/increments that exceed the amount lost, system capacity expansion differences among the alternatives do not typically match the amount of lost capacity. Appendix K, Section K.1.10.2, provides more details and illustrations of alternative impacts on capacity expansion timing and total new construction.

It is assumed that WAPA's eight largest wholesale customers make decisions and function as a single aggregate system, and that they would build enough capacity to reliably meet their total aggregate demands. The modeling of this power system assumes a very high level of cooperation and coordination among WAPA and its LTF power customers. Capacity expansion planning, unit commitment schedules, and least-cost hourly dispatch for the entire system were based on a "single operator/decision maker" model. This is a higher level of cooperation and coordination than what actually occurs and may tend to underestimate capacity replacement costs (or, in the case of Alternative B, benefits). On the other hand, because of siting, permitting, licensing, consruction time, and other factors, it may not be possible to bring units online as soon as indicated by the models. Later capacity replacement dates would lower the NPV of capacity replacements.

4.13.2.3 Economic Impacts

This section presents the anticipated economic impacts of LTEMP alternatives on hydropower resources. Included is a discussion of energy and capacity costs of operational characterisitcs of the LTEMP alternatives, the cost of experiments under Alternative D, and the results of sensitivity analyses performed to determine the effects of modeling assumptions on model results. The impacts of Alternative D on hydropower resources that are presented in this section were based on modeling performed prior to several changes in Alternative D, including an increase in the August volume (from 750 to 800 kaf in an 8.23-maf year, and a corresponding 25-kaf decrease in both May and June [changed from 657 to 632 kaf and 688 to 663 kaf, respectively] with proportional changes in drier and wetter years), reduction in the number of spring HFEs based on the prohibition of spring HFEs in the same water year as extended HFEs, and elimination of experimental load-following curtailment after fall HFEs. For hydropower resources, these adjustments to Alternative D would reduce the percent difference relative to Alternative A from 0.29% to 0.17%..

Energy and Capacity Costs

The power systems economic analysis primarily measures the impacts of LTEMP alternatives on the cost of generating energy to meet system electricity demands and to build sufficient capacity to meet these demands reliably. In doing so, the analysis accounts for system interactions and reactions. For example, when Glen Canyon Dam increases its output, power models estimate the generation response (i.e., decrease) of other online powerplants in the system. The economic impacts are not limited to any one individual system component, but rather to the collective impacts on all components in the system over the entire study period. Impacts measured include production costs that are incurred hourly on a continuous, ongoing basis and capacity expansion costs that occur as needed, and are therefore much less frequent. Focus is also placed on economic differences among alternatives rather than on their absolute values. Comparative analyses such as this one usually reduce modeling errors such as assumptions about high levels of system cooperation because errors occur in all alternatives and tend to cancel (or diminish) in the final calculations.

Capacity expansion cost components include capital investment costs, interest, and other expenses that are accrued during the time period that a generating unit is constructed ,in addition to fixed O&M costs that are incurred after the powerplant has been constructed. Since newly constructed capacity will operate long past the end of the 20-year LTEMP period, these costs along with interest during construction (IDC) are annualized and incurred from the time the unit comes on-line until the end of the study period. Similarly, O&M costs for new units are only incurred during the study years that the units operate. Because the primary focus of the analysis is on cost differences among alternatives, fixed O&M costs for existing powerplants are not included. It is assumed that these costs are identical among all alternatives because the AURORA model retirement schedule is identical across all alternatives.

The cost of serving system loads (system production cost) under each alternative over the 20-year LTEMP period is shown in Table 4.13-1. Costs are expressed in NPV to allow differences in the timing of generation to be normalized, using a 3.375% discount rate. Except for Alternative B, total energy production cost would increase under all alternatives compared to Alternative A, with increases varying from $21 million (a 0.06% increase) under Alternative E to $145 million (a 0.4% increase) under Alternative F. System-level production cost differences are a function of timing and routing of Glen Canyon Dam water releases and reservoir pool elevation effects.

In general, turbine water releases and associated generation occur when they have the highest economic value to decrease overall systemwide production costs. System energy value in this context is the amount of money that is expended to serve all of the system electricity demand. When the demand is low, it is served by generating units that have low production costs; however, as electricity demand increases, units that are more expensive to operate are brought on-line to serve this higher (or incremental) load. Therefore, there is a direct relationship between the cost of serving more demand and the incremental cost to serve it. In this economic analysis, the incremental cost to serve one more MWh of demand, electricity price, and economic value are used synonymously.

When Glen Canyon Dam produces energy during periods of the year when loads and prices are high, the power its produces offsets generation from more expensive units that would have otherwise been utilized. In effect, this lowers overall system production costs. Likewise, system production costs are lower when Glen Canyon generates energy during times of the day when it has the highest economic value. Alternatives with the most operational flexibility also have the highest economic value. This flexibility allows Glen Canyon Dam operators to generate more energy (that is, release more of the limited water resource) during times of the day when prices are highest and reduce generation when prices are low. Appendix K, Section K.1.10, provides more details on market prices and the timing of Glen Canyon Dam power production under each alternative.

Last, it should be noted that because water releases are limited, releases that bypass the generators (such as in the case of most HFEs) not only have zero power system economic value during the time of release, but also reduce future turbine water releases, and hence both energy production and value. In summary, the economic value of Glen Canyon Dam power generation is highest when water is released through powerplant turbines to produce energy which offsets generation that would have otherwise been produced by generating units that are expensive to operate. The economic impacts of HFEs and other experiments, including low summer flows, TMFs, and sustained low flows for invertebrate production, are included in the impact estimates under each alternative and bundled with all other cost components into a single NPV cost.

The cost of building new capacity (or capital costs) to meet the 15% system reserve margin discussed in the previous section is shown in Table 4.13-1. The table also shows fixed O&M costs associated with the new construction. Both costs are expressed in NPV.

Based on AURORA model runs and a review of both WAPA's customers' IRPs and the IRPs of surrounding utility systems, new capacity additions consist of advanced natural gas-fired combined cycle plants (400 MW) and advanced natural gas-fired combustion turbines (230 MW). Capacity expansion pathways are carefully chosen for each alternative and consist of a mix of new technologies that is consistent with those found in the IRPs of WAPA's large customers and also with Energy Information Administration (EIA) forecasts of future generation capacity in the Western Interconnection (see Appendix K, Section K.1.6.2, for more details).

Total cost, including capital, fixed O&M, and production costs, is shown in Table 4.13-1. The cost is expressed in NPV using a 3.375% discount rate. Based on representative hydrological conditions, the total system cost to reliably supply electric demand during the 20-year LTEMP period under Alternative A would be just over $36.2 billion, with a decrease of about $16 million (or 0.04%) in the cost under Alternative B. Although Alternative B has slightly lower monthly generation than Alternative A, its total system cost is lower because it has a higher firm capacity. The higher firm capacity delays the construction of a natural gas combustion turbine plant by a year compared to Alternative A. With slightly higher spring and slightly lower summer average daily flows under Alternatives C, D, E, and G compared to Alternative A, total costs would be slightly higher, ranging from about $36.3 billion under Alternatives D and E (an increase of about 0.3% compared to Alternative A) to over $36.6 billion under Alternative F (an increase of 1.2%), which would have higher spring and early summer flows, and lower late summer and fall flows, than Alternative A.

The local value of only Glen Canyon Dam energy production under each alternative is presented in Table 4.13-1. It is based on hourly Glen Canyon Dam generation levels and the local value of energy from the dam. The ranking and cost differences among these alternatives for this local value do not match overall system results because they only focus on Glen Canyon Dam. There is no consideration of system-level interactions and reactions. Note that capital and fixed O&M costs are also not included. All alternatives have reductions in the local value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period compared to Alternative A. Smaller reductions in value occur under Alternatives B, C, D, and E; losses in value vary from $5 million (a 0.2% reduction) under Alternative B to $49 million (a 1.9% reduction) under Alternative D. Alternatives F and G have larger reductions in value; namely, $122 million (a 4.6% reduction) and $106 million (a 4.0% reduction), respectively.

Cost of Experiments

A technique to "unbundle" the economic costs of several types of experiments was developed. Estimates of the cost of experiments were computed by comparing the estimated effects of long-term strategies of alternatives that differ only in inclusion of a particular experiment. The one element that differs between the two alternatives is the element for which the economic impacts are measured. For example, to measure the economic cost of low summer flows, two long-term strategies[31] for Alternative D are compared: long-term strategies D1 and D4. Both have identical operating criteria and the same experimental elements, except that under long-term strategy D1 low summer flows are included in the second 10 years of the LTEMP period, while under long-term strategy D4 low summer flow experiments would not be conducted. Subtracting NPV results for long-term strategy D4 from long-term strategy D1 yields the NPV cost of conducting the experiments over the 20-year LTEMP period. Using this methodology, the approximate cost of conducting different types of experimental elements can be "unbundled" from the total aggregate costs. The economic evaluations from the Structured Decision Analysis (Appendix C) provided the basis for this analysis because it modeled all 19 alternatives and long-term strategies.

The estimated NPV cost for each low summer flow experiment ranges from $21.01 million under Alternative D to $13.93 million under Alternative E.The NPV cost for each TMF on average ranges from $0.41 million under Alternative E to $0.45 million under Alternative D. The average NPV cost of each fall HFE ranges from $1.62 million under Alternative C to $1.65 million under Alternative E.

Macroinvertebrate production flows would, on average, increase the combined energy and capacity value by about $1.62 million per 4-month experiment. This experiment results in an increase because in the months of May through August, weekend flows are limited to the minimum flow for that month. Because there is no change in monthly releases for this experiment, lower weekend water releases result in larger water releases, more electric generation, and higher capacity on weekdays when demand and value is higher.

Additional discussion of the cost of experiments is presented in Section K.1.10.3 of Appendix K.

Sensitivity Analyses

Sensitivity analyses were performed on assumptions related to several factors including exceedance values, discount rates, capacity expansion pathways, hydrology, and ancillary services assumptions. These sensitivity analyses estimated how much the results would change if different assumptions were made regarding these factors. Of the factors evaluated, the type of technology used to replace lost capacity, exceedance value, and discount rate had the largest impact on the cost of generation and capacity. In most cases, the relative ranking of alternatives

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[31] See Section 4.1 and Appendix C for descriptions of the long-term strategies analyzed for the LTEMP EIS and their relationship to the LTEMP EIS alternatives.

was unaffected by the assumptions used, but the absolute cost levels were either higher or lower than those presented for the baseline in the previous section. Details of these analyses and results are presented in Appendix K (Sections K.1.10.4 through K.1.10.9).

Exceedance Level. The sensitivity analysis for exceedance level was based on the relatively detailed AURORA modeling approach. It compares the baseline 90% exceedance level (i.e., the amount of capacity that is available 90% of the time) to 50% and 99% exceedance levels (i.e., the amount of capacity that is available 50% and 99% of the time, respectively). The higher the exceedance level, the lower the firm capacity credit assigned to SLCA/IP federal hydropower resources. In addition, in the 50–99% exceedance range, the higher the exceedance level, the lower the firm capacity difference among alternatives. Therefore, the higher the exceedance level, the smaller the difference in capital and fixed O&M costs among alternatives. Change in capacity expansion also impacts system production costs, but this tends to have only minor impacts. At 50% exceedance, the NPVdifference compared to Alternative A increased by $0 to $71 million (or 0% to 79%), depending upon the alternative. At 99% exceedance, the cost difference compared to Alternative A decreased by $0 to $59 million (or 0% to 60%), depending upon the alternative. The relative ranking of alternatives changed only slightly across the three exceedance levels. Alternatives D and E switched places at both the 50% and 99% exceedance levels. At 90% exceedance, Alternatives D and E were the fourth and third lowest, respectively, but at both the 50% and 99% exceedance levels they were third and fourth lowest, respectively.

Discount Rate. The discount rate is the rate of return used to make the value of costs or benefits that occur at different points in time commensurate with each other. The sensitivity analysis for discount rates was based on the AURORA modeling approach. To determine the sensitivity of results to discount rate, a model run was made using a discount rate of 1.4% and compared to results for the baseline discount rate of 3.375%. When using a lower discount rate, the NPV costs of alternatives relative to Alternative A are larger because costs at the end of the study period have a larger contribution to the NPV. The costs increase by about $4 to $84 million (or 20% to 25%), depending upon the alternative; the greater an alternative's cost difference relative to Alternative A, the greater the cost increase with the lower discount rate. However, the relative ranking of alternatives and relative percent difference from Alternative A did not change for these two discount rates.

Expansion Pathway. The expansion pathway for an alternative describes the size, timing, and type of generating units that would be constructed over a specified planning horizon. Sensitivity analyses of the expansion pathway were performed using two methodologies; one used the AURORA model and the other the GTMax-Lite model. They each explored different aspects of changes in the power system expansion and their effect on costs and rankings of alternatives.

Base Expansion Mix. A sensitivity analysis was performed on the baseline capacity expansion path using the AURORA model. In the baseline expansion, both advanced combustion turbines and advanced combined cycle units were chosen by AURORA for new future additions under Alternative A. This is referred to as the base pathway. Adjustments to the timing and number of new advanced combustion turbines were then made to the base pathway to accommodate changes in Glen Canyon Dam capacity under the other alternatives.

The sensitivity study tested two extreme pathways for Alternative A. One base pathway built exclusively advanced combustion turbines and the second one built exclusively advanced combined cycle plants. The base construction pathway (i.e., the type and timing of additions) for Alternative A was used as the starting point for each of the other alternatives. Advanced combustion turbines were added to (or in the case of Alternative B, subtracted from)[32] a base expansion pathway to accommodate capacity changes at Glen Canyon Dam. Costs of the alternatives for each pathway varied slightly, both higher and lower, from the baseline expansion; there was no consistent trend toward higher or lower values in either of the two extreme base pathways as compared to the mixed pathway used for the baseline. Relative to the baseline pathway, the advanced combustion turbines yielded NPV changes that ranged from a decrease of $36 million (less expensive to implement than the alternative) for Alternative F to an increase of $15 million for Alternative C (more expensive). The advanced combined cycle sensitivity analysis produced NPVs that were between $27 million lower (Alternative G) and $51 million higher (Alternative D) than the baseline. These fluctuations in cost are primarily due to the lumpy nature of capacity additions. Alternative rankings for both pathways remain basically the same as the baseline.

Capacity Replacement Technology. A sensitivity analysis was performed on the baseline capacity replacement technology using the GTMax-Lite model. All lost capacity replacements under the baseline and sensitivity analyses described above relied exclusively on the advanced combustion turbine technology. However, models make many simplifying assumptions, and may not consider other factors beyond cost that a utility may use when determining thermal power plant additions. Consequently, a sensitivity analysis was performed to address uncertainties regarding the replacement of future capacity replacement.

The analysis considered a separate case in which capacity expansion changes relative to Alternative A would be made using a mix of 60% advanced natural gas combined-cycle plants and 40% advanced combustion turbines in terms of megawatts of capacity. This mix is approximately equal to the current average thermal capacity expansion mix contained in the IRPs of WAPA's LTF customers and other utilities in the surrounding area. It was derived from a review of IRPs that were available online in May 2016. Attachment K.11 of Appendix K provides a summary of capacity additions through the end of calendar year 2034. The GTMax-Lite model was used for this sensitivity analysis because it can exactly match the desired mix of capacity replacements. In addition, GTMax-Lite runs more rapidly with far fewer resources than AURORA, yet it produces similar results in terms of both differences in total NPV among alternatives and alternative ranking.

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[32] This involved building combustion turbines sooner and/or building more combustion turbine capacity for an alternative as compared to Alternative A. Under Alternative B, the construction of a combustion turbine was delayed.

Using a mix of 60% natural gas combined-cycle plants and 40% combustion turbines for capacity replacement increases costs relative to the baseline for all alternatives except for Alternative B. Alternative B has a lower NPV of approximately $11.0 million, while the costs for all other alternatives increase from $17.1 million under Alternative D (the Preferred Alternative) to $93.4 million under Alternative F. The new mix of capacity replacements does not change alternative rankings.

Hydrological Condition. In this case, hydrologic condition refers to the daily, monthly, and yearly pattern of dam releases under different simulated 20-year periods that are based on the historical record. A sensitivity analysis was performed on hydrology assumptions using the AURORA model. As discussed earlier, Trace 14 was selected as the representative trace and used for the AURORA dispatch run for the baseline analysis. Because impacts of alternatives are dependent on hydrology condition, a study was performed on the sensitivity of results to hydrological condition. An additional hydrological condition was run; this condition used the average hourly generation from all 21 traces as projected by GTMax-Lite runs. Capital and fixed O&M costs were identical for both hydrology conditions and there were only slight differences in the production costs. Differences in NPV relative to the baseline ranged from a cost decrease of $15 million under Alternative G to a cost increase of $18 million under Alternative F.

Ancillary Services. Ancillary services are electricity grid services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system (FERC 1995). Services include spinning reserve, non-spinning reserve, replacement reserve, regulation/load following, black start, and voltage support. A sensitivity analysis was performed on ancillary service assumptions for Alternatives A, D, and F using the GTMax-Lite model. Ancillary services included in this analysis consisted of regulation and fast spinning reserves. It was performed on two possible cases: one in which total ancillary services requirements would increase from 103 MW in 2013 to 160 MW by 2030, and another where the current level of 67 MW would remain the same during the entire LTEMP study period. The analysis showed firm capacity and energy at capacity exceedance levels of 50, 90, and 99% would differ by less than 0.8% under low and high ancillary services levels. The difference in total NPV between the two scenarios for Alternatives A and D is $2.8 million (0.08%) and $4.71 million (0.14%), respectively. There is no difference in total NPV between scenarios for Alternative F.

4.13.2.4 Change in FES Wholesale Rates

Through some combination of changed SLCA/IP rates under the No Change (NC) bookend or lower SLCA/IP commitment levels under the Resource Available (RA) bookend, FES utilities that receive SLCA/IP preference power will be impacted as a result of changed operations at Glen Canyon Dam. Under the NC bookend, WAPA would absorb the economic costs (or reap the benefits) of an alternative and adjust FES rates accordingly, passing costs/benefits to its customers. At the other end of the spectrum, SLCA/IP commitment levels would be adjusted to reflect hydropower resource attributes/capabilities under the RA bookend and FES customers would respond through adjustments to their system dispatch and future resource expansion paths.

For each alternative, WAPA computed the impact of each alternative in terms of single energy and capacity rates that are applied over the entire 2015 through 2034 LTEMP period. This deviates from WAPA's normal 5-year forecast in order to accurately capture each alternative's rate impacts. Table 4.13-1 shows FES customer rates estimated by WAPA RPS studies under both NC and RA bookend marketing structures. The energy and capacity rates reflect WAPA's current method of setting FES rates. SLCA/IP FES customers are billed monthly for the amount of energy used and for their capacity allocation. See Appendix K, Section K.2, for more detailed information on FES wholesale rate results.

This analysis is not a description of policy or an attempt to predict WAPA's post-2024 marketing plan. This set of bookend results is intended to reflect the range of reasonable possibilities.

4.13.2.5 Retail Rate and Bills Impacts

Systemwide production costs, fixed operation and maintenance costs of new capacity and the financing cost associated with building new plants is assumed to be incurred ultimately by entities that receive SLCA/IP preference power.[33] Costs associated with replacing generation capacity no longer provided at Glen Canyon Dam ultimately increases retail rates and bills of residential and non-residential customers. The retail rate impacts experienced by utility systems are not uniform across different utility systems that receive federal preference power. Differential retail rate impacts on particular systems from LTEMP alternatives are largely driven by the amount of power that is allocated from SLCA/IP relative to the quantity of other power that is produced or purchased by a particular system. If utility systems are allocated a large amount of SLCA/IP capacity and energy, but because of their large size, this allocation is a small fraction of the overall amount of power purchased, the retail rate impacts tend to be small. The relative dependence on SLCA/IP capacity and energy varies by a wide margin across entities that receive allocations. SLCA/IP energy allocation as a percent of retail sales range from 0.05% for SRP up to 62% for the City of Meadow (a member of UAMPS). Impacts on the utility systems that are most impacted are presented in Appendix K, Section K.3. This appendix also describes impacts on Tribal systems.

Table 4.13-1 shows impacts on retail electric rates and monthly residential electricity bills for WAPA's preference power customers compared to Alternative A. The change in retail rates and the average change in monthly residential bills are both in the year of maximum rate impact. Both metrics are not weighted by utility size; that is, each utility serving retail customers has the same weight. Note that the estimated retail rate impacts presented here were derived independently by Argonne and did not use the wholesale rates described in Section 4.13.2.4 as input. Wholesale rates were not used because: (1) by using data from the power systems model,

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[33] The cost of experimental releases such as HFEs are currently considered to be non-reimbursable expenses.

the direct connection between power system costs and rate impacts could be observed and the process was transparent; and (2) the capital cost of constructing new capacity incurred by utility systems was directly estimated rather than assuming WAPA would carry the burden of replacing the capacity. Retail rate impacts were directly computed from projected wholesale power costs derived from the power systems analysis in Section 4.13.2.3. Rate impact calculations were based on the assumption that the capital, operating, and administrative costs of Glen Canyon Dam operations do not substantively change under different LTEMP alternatives when the energy output from the dam changes. These costs are not expected to be affected by differences in operations under LTEMP alternatives. Because these operating and administrative costs are not affected by the LTEMP alternatives, rate impacts result from changes in the cost associated with replacing capacity and/or energy with changes in dam operations. This approach may have produced somewhat higher estimates of retail rate impacts than if the wholesale rate impacts developed by WAPA in Section 4.13.2.3 had been used. More detailed analyses of retail rates and residential bills are provided in Appendix K, Section K.3.

The average change in the retail rate varies from a decrease of 0.27% in Alternative B to an increase of 1.21% in Alternative F. The average change in the monthly residential electricity bill varies from a decrease of $0.27 in Alternative B to an increase of $1.02 in Alternative F. Both metrics are the average in the year of maximum rate impact and are therefore higher than the average impact over the study period. The electric bill reduction in Alternative B is due to a delay of one year in constructing a new natural gas-fired combustion turbine compared to Alternative A. Similarly the electric bill increase in Alternative F is due to the construction of two new natural gas-fired combustion turbines over the 20-year LTEMP period compared to Alternative A. Retail rate and residential bill impacts are computed from adjusting data in the power systems analysis for municipal and cooperative carrying costs and not from SLCA/IP wholesale prices. If estimated wholesale prices are used instead of adjusting power systems cost, the measured rate impacts would be lower.

4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power Economics

Hoover Dam operating criteria are unaffected by LTEMP EIS alternatives. Its energy production and economic value, however, will be impacted primarily by temporary changes in Lake Mead elevation that are projected to occur within a water year. In addition, alternatives will occasionally result in reallocation of Lake Mead monthly water release volumes within a year, when changes in projected December end-of-month elevations result in a different operating condition, which would also affect Hoover Dam power economics. The Hoover Powerplant Model used projected Lake Mead reservoir elevations over the 20-year LTEMP period to estimate the monthly maximum operational capacity for the Hoover Powerplant for all 21 hydrology traces. Assuming the firm capacity at the Hoover Powerplant is based on the 90% exceedance level in the peak load month of August, the model found that for all alternatives the Lake Mead elevation is below the minimum pool level of 1,050 ft more than 10% of the time. Therefore, because more than 10% of the time in August no generation is possible, no firm capacity (or a firm capacity of zero) was assigned to all of the alternatives (see Section K.5 in Appendix K).

The Hoover Powerplant Model computed the change in economic value of Hoover Powerplant energy production attributed to each LTEMP alternative by multiplying the change in monthly energy production by monthly market prices of energy as projected by the AURORA model. Estimates are made for each month of the 20-year LTEMP period for all 21 hydrology traces. To compare LTEMP alternative economics on a consistent basis, the NPV of Hoover Dam energy was computed using a 3.375% annual discount rate, which is the same rate used for computing the NPV of SLCA/IP costs. The NPV of Hoover Powerplant energy is shown for each alternative in Figure 4.14-4 and presented in Table 4.13-1. The increase in NPV for Hoover Dam energy, relative to Alternative A, ranges from nearly zero for Alternative B to about $89 million for Alternative F.

As discussed in more detail in Section K.5 of Appendix K, the model used to compute Hoover Dam energy value considered fewer factors than the one used to estimate impacts at Glen Canyon Dam. For example, Hoover Dam estimates primarily use a monthly time step, while Glen Canyon Dam estimates are based on a model that optimizes hourly operations. In addition, Hoover Dam model results are highly sensitive to assumptions, particularly the assumed minimum power pool elevation, which affects the economic results for both energy and firm capacity because most of the estimated increases in value are due to lower non-power releases under LTEMP alternatives.

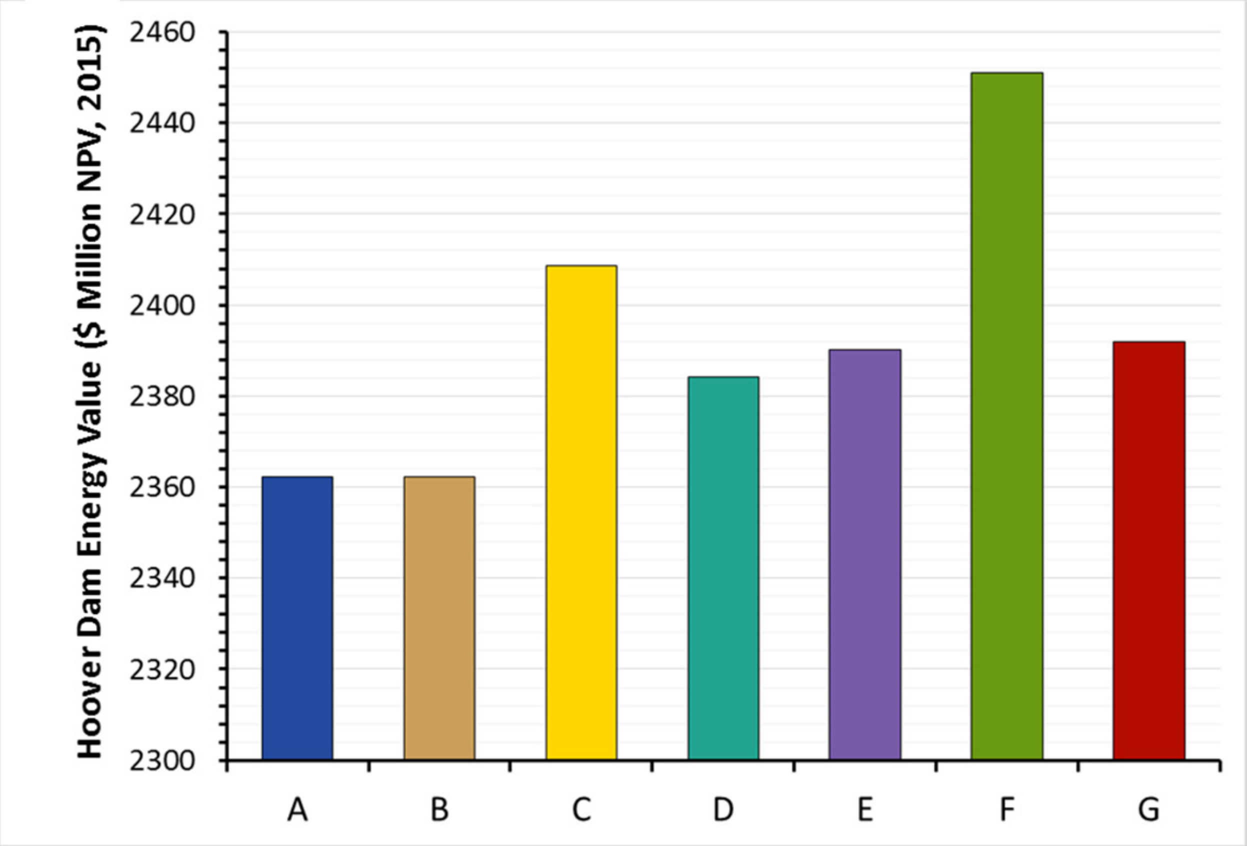

FIGURE 4.13-3 Total NPV of Hoover Powerplant Energy over a 20-Year Period under LTEMP Alternatives

4.13.3 Alternative-Specific Impacts

4.13.3.1 Alternative A (No Action Alternative)

Average annual daily generation at Glen Canyon Dam is currently 11,599 MWh under representative hydrological conditions. Average daily generation ranges from 8,640 MWh in March to 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to 11,606 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,662 million, and would not change under Alternative A. SLCA/IP marketable capacity is currently 737.2 MW at the 90% exceedance level. Average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity would not change under Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity built under Alternative A over the 20-year LTEMP period. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative A would be just over $36.2 billion.

Because there would be no change in Glen Canyon Dam operations as a result of Alternative A, there would be no impact on the wholesale rates WAPA charges its FES utility customers, retail rates charged by WAPA's customer utilities, or the electric bills paid by their residential customers. The average wholesale energy rate of the two bookend cases was estimated to be $13.46/kWh and the average capacity rate was estimated to be $5.72/kW.

In summary, Alternative A would have the second-highest firm capacity from SLCA/IP and tied with Alternative B for the smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the second-lowest total cost to meet electric demand over that period, and there would be no change in either the average electric retail rate or the average monthly residential electricity bill. There would be no change in the value of generation produced at Hoover Dam.

4.13.3.2 Alternative B

Average annual daily generation at Glen Canyon Dam would be 11,567 MWh under representative hydrological conditions. Average daily generation under representative hydrological conditions would range from 8,665 MWh in March to 15,405 MWh in August, before falling to 9,046 MWh in November, and then increasing to 11,608 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,657 million, a decrease of $5 million, or 0.2%, compared to Alternative A as explained below. SLCA/IP firm capacity would be 765.3 MW at the 90% exceedance level, which is a 28 MW, or 3.8%, increase compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and a slight increase in SLCA/IP firm capacity under Alternative B compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity built under Alternative B over the 20-year LTEMP period. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet electric demand under Alternative B would be $36.2 billion.

Under Alternative B, there would be a small reduction in capital and fixed O&M costs associated with new capacity relative to Alternative A. Although the total amount of capacity added over the 20-year LTEMP period is the same as Alternative A, there would be a 1-year delay in constructing a new natural gas-fired combustion turbine. This delay accounts for the slightly lower total cost of Alternative B compared to Alternative A. Also because of the construction delay, the average electricity retail rate could drop by 0.27% and the average monthly residential electricity bill could be reduced by an average of $0.27. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.38/kWh, which is a decrease of $0.08/kWh (–0.6%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.69/kW, which is a decrease of $0.03/kW (–0.5%) compared to Alternative A.

The economic value of energy produced at Hoover Dam under this alternative would be the same as under Alternative A over the 20-year LTEMP period because there would be no difference in monthly releases between the two alternatives.

In summary, Alternative B would have the highest firm capacity from SLCA/IP federal hydropower resources of any alternative and would be tied with Alternative A for the smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would decrease compared to Alternative A. There would be a decrease in the average electric retail rate and in the average monthly residential electricity bill compared to Alternative A in the year of maximum rate impact. There would be no change in the value of generation produced at Hoover Dam compared to Alternative A.

4.13.3.3 Alternative C

Average annual daily generation at Glen Canyon Dam would be 11,506 MWh under representative hydrological conditions. Average daily generation under would range from 10,292 MWh in February to 14,855 MWh in July, before falling to 7,971 MWh in October, and then increasing to 11,739 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,614 million, a decrease of $48 million, or 1.8%, compared to Alternative A. SLCA/IP firm capacity would be 608.1 MW at the 90% exceedance level, which is a 129-MW, or 17.5%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity under Alternative C compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative C over the 20-year LTEMP period. An additional gas turbine would be needed during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative C would be almost $36.4 billion. Including the estimated cost of experimental low summer flows would result in an average increase in cost of about $24.5 million over a 20-year period, assuming the average number of low summer flows anticipated to be triggered (1.8). This would not change the relative rank of Alternative C compared to other alternatives.

Because of the additional gas turbine the average retail electric rate would increase about 0.43% and the average monthly residential electricity bill would increase by an average of $0.40. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $14.27/kWh, which is an increase of $0.81/kWh (6.0%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.06/kW, which is an increase of $0.35/kW (6.0%) compared to Alternative A.

The NPV of energy produced at Hoover Dam under this alternative is $46 million more than that under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations, which result from changes in monthly water releases upstream at Glen Canyon Dam.

In summary, Alternative C would have the fifth-highest firm capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the fifth-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A. It would have the fourth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the second-largest increase in the value of generation at Hoover Dam compared to Alternative A.

4.13.3.4 Alternative D (Preferred Alternative)

Average annual daily generation at Glen Canyon Dam would be 11,477 MWh under representative hydrological conditions. Average daily generation would range from 9,392 MWh in February to 14,051 MWh in July, before falling to 10,381 MWh in October, and then increasing to 11,052 MWh in November (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,613 million, a decrease of $49 million, or 1.8%, compared to Alternative A. SLCA/IP firm capacity would be 687.6 MW at the 90% exceedance level, which is a 49.6 MW, or 6.7%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity under Alternative D compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative D over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative D would be just over $36.3 billion.

Because of the additional gas turbine the average retail electric rate would increase about 0.39% and the average monthly residential electricity bill would increase by an average of $0.38. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.86/kWh, which is an increase of $0.4/kWh (3.0%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.89/kW, which is an increase of $0.17/kW (3.0%) compared to Alternative A.

As noted in Section 4.13.2.3, a technique was used to "unbundle" the economic costs of several types of experiments so the cost of each experiment could be estimated. Alternative D has low summer flows, TMFs, macroinvertebrate production flows, and both spring and fall HFEs.

The estimated average NPV cost for each low summer flow experiment in Alternative D is $21.01 million. This value includes an NPV energy cost of $2.76 million and a capacity cost of $18.25 million (see Table K.1-11 in Appendix K). Each TMF in Alternative D has an average energy cost of $0.45 million; there is no capacity cost because TMFs do not occur in August and monthly reallocations of water are not required to support these experiments.

Each 4-month macroinvertebrate production flow experiment has, on average, a net increase in value of $1.62 million, which consists of an energy value decrease of $871,000 and a capacity value increase of $2.49 million. The capacity increase occurs because water releases are minimized on weekends, which makes more water available for power production during weekdays when the peak load would most likely occur. The estimate provided here differs from that presented in the DEIS. After the DEIS was published, discussions with WAPA indicated that they would implement macroinvertebrate production flows in a different way than under normal operations, and the difference would maximize the benefit of lower weekend flows and capacity production during weekdays. Rather than a net cost of macroinvertebrate flows as presented in the DEIS, a net benefit to hydropower generation and capacity would be realized.

Finally, the average cost for each fall HFE ≤96 hr for Alternative D (based on an average of HFEs from the long-term strategies analyzed) is expected to range from approximately $1.62 million to $1.65 million (average of $1.64 million). The cost of fall HFEs consists of an energy component only because they do not occur in August and do not affect monthly water releases during August. Assuming a cost of a fall HFE under Alternative D of $1.64 million, the per-hour cost would be $17,083 and the total cost for the longest possible extended-duration fall HFE (250 hr) would be $4.27 million. Note that this estimate assumes the costs for each hour would be equal, but in reality there would be some hours of ramp up and ramp down at the beginning and end of the HFE when cost would be less. In addition, a 250-hr HFE would have some additional cost associated with reducing reservoir elevation more than a 96-hr HFE. The cost of a spring HFE is expected to be similar in cost to a fall HFE.

The NPV of energy produced at Hoover Dam under this alternative is $22 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations resulting from the monthly water releases upstream at Glen Canyon Dam.

The results presented in Table 4.13-1 are from modeling conducted prior to making the adjustments to Alternative D described in Section 2.2.4, including prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE; elimination of experimental load-following curtailment after fall HFEs; and an adjustment in the monthly release volumes. Based on these modifications, the actual number of HFEs would be about 19.8 (1.3 fewer), which is estimated to reduce the cost of the alternative on hydropower generation by about $2.1 million over a 20-year period, using the estimated cost of HFEs presented in Section K.1.10.3.

Based on modeling that was performed after the DEIS was published,[34] the change in monthly release volumes would result in decreases in the NPV of the cost of production and capacity of about $5.3 million and $27.6 million, respectively, over the 20-year period. Elimination of load-following curtailment would result in a decrease in NPV of the production cost of about $4.0 million over the 20-year period, but would have no effect on capacity.

In addition to these adjustments to Alternative D, changes in the way macroinvertebrate production flows would be implemented and inclusion of the cost of low summer flows in the total cost of Alternative D would result in changes to the estimated total cost of Alternative D. Implementation of experimental macroinvertebrate production flows were modified based on input from WAPA after the DEIS was published. As described above, this modification would result in a net reduction in cost of individual experiments, producing a total reduction in cost of $19.8 million over a 20-year period rather than the original estimated increase of $94 million. Including the costs of low summer flows results in an average increase in cost of about $15.0 million over a 20-year period assuming the average number of low summer flows anticipated to be triggered (0.714).

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[34] This modeling was performed using the screening tool described in Section 2.1, whose hydropower module was based on the GTMax-lite model, but incorporated several simplifying assumptions (e.g., constant flow to power conversion factor, constant within-month daily generation pattern). Unlike the modeling used to estimate costs of alternatives on energy and capacity shown in Table 4.13-1, which used GTMax-lite and Aurora models to estimate systemwide effects of LTEMP alternatives, the modeling used to estimate the effects of Alternative D adjustments focused only on Glen Canyon Dam energy and capacity rather than systemwide effects.

The cumulative effect of all of these adjustments and inclusion of low summer flows may reduce the total cost of Alternative D by approximately $44 million over a 20-year period; the original estimated increase in cost of $104 million relative to Alternative A would be reduced to $60 million. These adjustments to Alternative D reduce the percent difference relative to Alternative A from 0.29% to 0.17%.

These estimates may differ from the results that would be obtained had the integrated modeling been used to assess modifications to Alternative D. The streamlined modeling results are, however, considered representative of the expected effects of the adjustments, and they are provided here as an estimate of the approximate magnitude of the effects these adjustments may have on the actual impacts of Alternative D. Because the streamlined modeling results show that the adjustments to Alternative D are small and positive (i.e., reducing the impact), further analysis under the integrated model would not produce information to assist in making a reasoned choice among alternatives, particularly given the time and cost of further integrated modeling. Alternative D was chosen as the preferred alternative based on the original modeling performed on Alternative D prior to making modifications. It was determined that Alternative D provided an appropriate balance between protection of downstream resources while minimizing impacts on hydropower. The streamlined modeling of the effects of adjustments indicates that those adjustments would continue to provide for the protection of downstream resources while reducing even further the effects of the alternative on hydropower.

In summary, Alternative D would have the third-highest firm capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also has the fourth-lowest total cost to meet electric demand over that period (third lowest, considering the effects of adjustments discussed above). Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A. It has the third-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the fifth-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.5 Alternative E

Average annual daily generation at Glen Canyon Dam would be 11,521 MWh under representative hydrological conditions. Average daily generation would range from 9,858 MWh in February to 14,352 MWh in July, before falling to 10,332 MWh in October, and then increasing to 11,008 MWh in January (Figure 4.13-2). The NPV of local electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,620 million, a decrease of $42 million, or 1.6%, compared to Alternative A. SLCA/IP firm capacity would be 647.0 MW at the 90% exceedance level, which is a 90 MW, or 12.2%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity under Alternative E compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative E over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative E would be just over $36.3 billion. Including the estimated cost of experimental low summer flows would result in an average increase in cost of about $9.95 million over a 20-year period, assuming the average number of low summer flows anticipated to be triggered (0.71). This would not change the relative rank of Alternative D compared to other alternatives (but note that other adjustments to Alternative D would change Alternative E's rank as described in the summary paragraph below).

Because of the additional gas turbine the average retail electric rate would increase about 0.50% and the average monthly residential electricity bill would increase by an average of $0.47. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.93/kWh, which is an increase of $0.47/kWh (3.5%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.92/kW, which is an increase of $0.2/kW (3.5%) compared to Alternative A.

The NPV of energy produced at Hoover Dam under this alternative is $28 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations resulting from the monthly water releases upstream at Glen Canyon Dam.

In summary, Alternative E would have the fourth-highest firm capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the third-lowest total cost to meet electric demand over that period (fourth lowest, considering the effects of Alternative D adjustments discussed above). Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A. It would have the fifth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the fourth-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.6 Alternative F

Average annual daily generation at Glen Canyon Dam would be 11,379 MWh under representative hydrological conditions. Average daily generation under representative hydrological conditions would range from 6,918 MWh in January to 19,995 MWh in June, before falling to 7,891 MWh in in October, and then increasing to 9,495 MWh in November and falling to 6,911 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year study period under representative conditions would be $2,540 million, a decrease of $122 million, or 4.6%, compared to Alternative A. SLCA/IP firm capacity would be 423.1 MW at the 90% exceedance level, which is a 314 MW, or 42.6%, decrease compared to Alternative A. There would therefore be large decreases in average annual daily generation in summer and winter months that have the highest electricity prices and a large decrease in SLCA/IP firm capacity under Alternative F compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,280 MW of new capacity built under Alternative F over the 20-year LTEMP period. Two additional gas turbines are built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative F would be just over $36.6 billion.

Because of the two additional gas turbines the average retail electric rate would increase about 1.21% and the average monthly residential electricity bill would increase by an average of $1.02. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $16.27/kWh, which is an increase of $2.81/kWh (21%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.91/kW, which is an increase of $1.2/kW (21%) compared to Alternative A.

The NPV of energy produced at Hoover Dam under this alternative is $89 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations resulting from the monthly water releases upstream at Glen Canyon Dam.

In summary, the operating constraints of Alternative F would require a steady flow from Glen Canyon Dam every month of the year. This alternative would have the lowest firm capacity (or the seventh highest) from SLCA/IP of all alternatives and the most new capacity needed over the 20-year LTEMP period. It also would have the highest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A; in fact, this alternative would have the largest increase in wholesale rates of all alternatives. It would the highest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.7 Alternative G

Average annual daily generation at Glen Canyon Dam would be 11,403 MWh under representative hydrological conditions. Average daily generation under would range from 8,932 MWh in February to 13,256 MWh in June, before falling to 8,827 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,556 million, a decrease of $106 million, or 4.0%, compared to Alternative A. SLCA/IP firm capacity would be 558.2 MW at the 90% exceedance level, which is which is a 179 MW, or 24.3%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and a large decrease in SLCA/IP firm capacity under Alternative G compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative G over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative G would be almost $36.5 billion.

While the capital and operating costs borne by WAPA customer utilities to replace generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by customer utilities under Alternative G and, consequently, changes in the electric bills of residential customers, impact on electric bills paid by residential customers of WAPA's customer utilities would be less than 1%.

Because of the additional gas turbine the average retail electric rate would increase about 0.64% and the average monthly residential electricity bill would increase by an average of $0.59. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $15.65/kWh, which is an increase of $2.19/kWh (16%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.67/kW, which is an increase of $0.95/kW (17%) compared to Alternative A.

Finally, the NPV of energy produced at Hoover Dam under this alternative is $30 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations that result from the monthly water releases upstream at Glen Canyon Dam.

In summary, the operating constraints of Alternative G would require a steady flow from Glen Canyon Dam every month of the year. This alternative would have the sixth-highest firm capacity from SLCA/IP of all alternatives (the second lowest after Alternative F) and would be tied for the third smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the sixth-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A; in fact, this alternative would have the second-largest increase in wholesale rates of all alternatives. It would have the sixth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the second-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE

This section describes the potential impacts of changes in dam operations on the recreational use values and nonuse values placed on recreational resources by individuals that visit, or may never visit, Lake Powell, Lake Mead, and the Grand Canyon. It also describes the potential regional economic impacts of changes in recreational visitation in a six-county region, and the potential impacts on low-income and minority populations in an 11-county region in the vicinity of the reservoirs and river corridor, and in eastern Arizona and northwestern New Mexico. The section also describes the regional economic impacts of changes in customer utility electricity bills and of expansion in electricity generation capacity that would occur as a result of changes in dam operations, as well as the potential impacts of changes in utility bills on low-income and minority populations, including Tribal populations, in the seven-state region in which power generated at the Glen Canyon powerplant is marketed.

Issue: How do alternatives affect socioeconomics and environmental justice?

Impact Indicators:

- Recreational use values associated with current and potential levels of visitation
- Nonuse (or passive use) economic value associated with the preferences of nonusers
- Employment and income impacts resulting from changes in recreational visitation, customer utility electricity generation capacity expenditures, and residential electricity bill expenditures
- High, adverse, and disproportionate impacts of changes in dam operations on low-income and minority populations

4.14.1 Analysis Methods

This section describes the methods used to estimate changes in recreational use values and non-use (or passive use) economic value that would result from changes in dam operations; the methods used to estimate the economic impacts of change in recreational visitation, customer utility electricity generation capacity expenditures, and residential electricity bill expenditures; and methods used to estimate the impacts of changes in dam operations on low-income and minority populations.

4.14.1.1 Recreational Use and Environmental Non-Use Values

The economic significance of recreational resources on the Colorado River can be measured both in terms of economic welfare, or consumer surplus, which is the amount of value a consumer of a good or service receives over and above that which would be paid for the good or service in the marketplace. However, as recreational activities are often not a market good, the characteristics of the demand for recreational resources cannot be based on the demand for recreational resources in the marketplace. Accordingly, consumer surplus is often referred to as *non-market value*, which includes both use value and non-use value (also called passive use value).

Estimation of recreational use values associated with potential changes in recreational resources under each of the alternatives relies on the benefits transfer method. This method involves the application of existing recreational use value estimates for a particular time period, site, level of resource quality, or combination thereof to a situation for which data are not available. The traditional benefits transfer approach to valuing recreation has been to employ existing use values studies conducted at an existing site, adjusting estimates to account for inflation. Transferring use value estimates from older studies rely on finding a study area with the same recreation activity in a similar geographic area as the study site, meaning that the preferred approach is to employ statistical recreation models developed for a study site; such models are used in conjunction with coefficients from an existing site to estimate recreation visitation and/or value at the study site, allowing the model transfer technique to improve the validity of the results compared to the use value transfer approach.

Because statistical models have been developed for estimating recreation value per trip for two of the three river reaches in the LTEMP study area—Glen Canyon and Upper Grand Canyon—and models estimating recreation use have been developed for Lake Powell and Lake Mead, while other studies have estimated values per trip for recreation use of Lake Powell and Lake Mead, the benefits transfer methods provides a useful and reliable approach to estimating river use values and reservoir visitation.

Visitation levels at the reservoirs were estimated using Neher et al. (2013) and then evaluated using the approach described in Gaston et al. (2014). The net economic value of recreation was then estimated for Lake Powell and Lake Mead, using the Lake_Full program; the GCRec_Full program was used to estimate the economic value for recreation on the three reaches of the Colorado River—Glen Canyon (from Glen Canyon Dam to Lees Ferry at RM 0), Upper Grand Canyon (from Lees Ferry to Diamond Creek at RM 225), and Lower Grand Canyon (from Diamond Creek to Lake Mead). These programs and the benefits transfer method are described in Appendix L. A review of use value estimates associated with Lake Powell, Glen Canyon, Upper Grand Canyon, Lower Grand Canyon, and Lake Mead can be found in Gaston et al. (2014).

In addition to use values, there may also be significant non-use values associated with reservoir and river resources in the Grand Canyon. A review of non-use valuation studies is provided in Section L.1.2 of Appendix L. NPS conducted a survey to determine non-use values associated with the impacts of Glen Canyon Dam operations on the endangered humpback chub, sandbars in the Grand Canyon, populations of large trout in Glen Canyon, and hydropower. The survey used a discrete choice model to estimate household and aggregate willingness to pay for various environmental outcomes associated with operations. These outcomes were then mapped to specific LTEMP alternatives to determine willingness to pay for each alternative. Survey data were collected from two samples of households—a national sample including all U.S. households, and a regional sample, including a sample of households purchasing power from Glen Canyon Dam. More information on the survey methods can be found in Neher et al. (2016), which is summarized in Appendix L.

4.14.1.2 Recreational Economic Impacts

The economic impacts of changes in recreational activity under each alternative are estimated using changes in visitor expenditures associated with various types of recreational activities, including angling, rafting, and boating, as well as spending on food and beverages, restaurants, fishing and boating equipment, gasoline for vehicles and boats, camping fees or motel expenses, guide services, and fishing license fees. Impacts occurring under each alternative are estimated for the six-county region in which the majority of recreational expenditures are likely to occur, and includes Coconino County and Mohave County in Arizona, and Garfield County, Kane County, San Juan County, and Washington County in Utah. Although a large number of visitors to Lake Mead come from the western side of the Colorado River in Clark County, Nevada, their share of expenditures on reservoir recreation in Clark County is not known. Expenditures are therefore assumed to occur in the six counties included in the analysis. Although the addition of Clark County to the analysis would likely produce slightly larger reservoir recreation employment and income impacts under each of the alternatives, it would not affect relative differences among the alternatives. Economic impacts include both direct and secondary effects of changes in expenditures that may occur on employment and income, and were estimated using the IMPLAN analysis tool (IMPLAN Group, LLC 2014). More information on the data and methods used, and a review of studies of the economic impacts of recreation activities in Glen Canyon, Grand Canyon and the surrounding area can be found in Section L.1.3 of Appendix L.

4.14.1.3 Electricity Bill Increase and Generation Capacity Expansion Impacts

Under each LTEMP alternative, the regional economic impacts of the eight largest WAPA customer utilities constructing and operating additional powerplants to replace energy and capacity losses from Glen Canyon Dam, and the resulting changes in customer utility electricity prices, were analyzed for the seven-state region in which WAPA markets power. This region includes Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming. Estimates of the required additional powerplant capacity were taken from the AURORAex model results (see Appendix K), and data on gas powerplant construction and operating expenditures, including materials, equipment, services, direct and indirect labor, by technology, size, and location were taken from the JEDI model (NREL 2015). Data on changes in retail electricity rates charged by the eight largest WAPA customer utilities, and the resulting changes in residential customer bills, were also included in the analysis (see Appendix K for a description of the retail rate analysis). IMPLAN input-output models (IMPLAN Group, LLC, 2014) (see Section L.1 of Appendix L), were used to estimate the regional economic impacts of additional generating capacity and changes in electricity prices; a separate IMPLAN model represents each of the seven states in the WAPA power marketing area. Note that the alternatives could affect the seasonal pattern of Lake Mead elevations, and thus power generation and capacity at Hoover Dam. However, such effects at Hoover Dam are anticipated to be relatively small (Section 4.13).

4.14.1.4 Environmental Justice

The analysis of potential environmental justice impacts follows guidelines described in the Council on Environmental Quality's (CEQ's) *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). Environmental justice impacts on Tribes could occur through impacts on Tribal values or through impacts on Tribal economics. Impacts on values could result from temporary changes in access to culturally important Tribal resources, and there may be an adverse impact on Tribal values from trout management actions. Tribal economics may be affected by alternative-specific differences in impacts on recreation in Glen Canyon and the Grand Canyon and in the surrounding area, or from changes in the retail rates of hydropower sold to Tribes.

The analysis of environmental justice issues considered impacts within the 11-county region in which disproportionately high and adverse human health and environmental effects on minority and low-income populations may occur (including Apache County, Coconino County, Mohave County, and Navajo County in Arizona; Cibola County, McKinley County, and San Juan County in New Mexico; and Garfield County, Kane County, San Juan County, and Washington County in Utah). Other potential impacts related to environmental justice include changes in Tribal electricity retail rates, and impacts on Tribal resources and values. Using CEQ guidelines, the impact assessment determined whether each alternative would produce impacts that are high and adverse. If impacts were high and adverse, a determination was made as to whether these impacts would disproportionately affect minority and low-income populations by comparing the proximity of locations where any high and adverse impacts are expected with the location of low-income and minority populations. If impacts are not high and adverse, there can be no disproportionate impacts on minority and low-income populations.

4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice

Table 4.14-1 summarizes the impacts for recreational use values, environmental non-use values, recreational economic impacts, and environmental justice.

4.14.2.1 Recreational Use Values

Recreational resources in Lake Powell, Lake Mead, and the Grand Canyon produce significant mean annual use values, with recreational activities in Lake Mead and Lake Powell constituting almost 97% of overall use value under each alternative (Table 4.14-2). Use values are presented in terms of net present value, to allow for differences in the distribution of use values between activities over time. Total mean annual use value created by all reservoir and river recreational activities amounts to $14,619.8 million under Alternative A (No Action Alternative), values which would decline slightly to between $14,598.7 million under

TABLE 4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and Environmental Justice[a]

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of socioeconomic impacts	No change from current conditions in use values, or economic activity with no change in reservoir levels or river conditions. Lowest non-use value of alternatives.	Compared to Alternative A, no change in use values and economic activity associated with Lake Powell recreation, and declines in use values (up to 5.2%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Minimal decrease in use values (less than 0.1%) and no change in economic activity associated with Lake Mead recreation. Minimal increase in economic activity (less than 0.1%) from lower residential electric bills compared to Alternative A.	Compared to Alternative A, declines (0.7%) in use values and economic activity (0.6%) associated with Lake Powell recreation, and in use values (up to 11.5%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity from higher residential electric bills (less	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 11.7%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity from higher residential electric bills (less	Compared to Alternative A, declines in use values (0.5%) and economic activity (0.5%) associated with Lake Powell recreation, and in use values (up to 14.0%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity from higher residential electric bills (less than 0.1%). Annual	Compared to Alternative A, declines in use values (1.1%) and economic activity (1.1%) associated with Lake Powell recreation, and in use values (up to 8.9%) associated with most forms of river recreation. Increase in use values (0.5%) associated with Upper and Lower Grand Canyon private boating. Decrease in economic activity for angling, with declines during HFEs. Increases in use values (0.5%) and economic activity (0.5%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 9.3%), and minimal decrease in economic	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 13.2%) associated with most forms of river recreation. Increase in use values (0.3%) associated with Lower Grand Canyon private boating. Decrease in economic activity for angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of socioeconomic impacts (Cont.)		Annual increase in non-use value of $1,511 million at national level.	than 0.1%). Annual increase in non-use value of $3,985 million at national level.	than 0.1%). Highest non-use value of alternatives. Annual increase in non-use value of $4,486 million at national level.	increase in non-use value of $3,963 million at national level.	activity from higher residential electric bills (less than 0.1%). Annual increase in non-use value of $2,353 million at national level.	from higher residential electric bills (less than 0.1%). Annual increase in non-use value of $3,524 million at national level.
Use Values[a]							
Lake Powell	No change from current conditions in use values ($5,016 million) because no change in water levels (lowest impact of alternatives).	Same as Alternative A	Compared to Alternative A, potential declines in use values of 0.7% (to $4,983 million) associated with lower water levels.	Compared to Alternative A, potential declines in use values of less than 0.4% (to $4,997 million) associated with lower water levels.	Compared to Alternative A, potential declines in use values of less than 0.5% (to $4,990 million) associated with lower water levels.	Compared to Alternative A, potential declines in use values of 1.1% (to $4,961 million) associated with lower water levels (highest impact of alternatives).	Compared to Alternative A, potential declines in use values of 0.4% (to $4,997 million) associated with lower water levels.
Glen Canyon	No change from current conditions in use values ($68.8 million) with no changes in river conditions (lowest impact of alternatives).	Compared to Alternative A, potential decline in use values for angling of 3.4% (to $19.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 6.2% (to $18.9 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 4.7% (to $19.2 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 3.4% (to $19.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 13.3% (to $17.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions (highest impact of alternatives).	Compared to Alternative A, potential decline in use values for angling of 6.2% (to $18.9 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Upper Grand Canyon	No change from current conditions in use values ($355.8 million) with no changes in river conditions (lowest impact of alternatives).	Compared to Alternative A, potential decline in use values for private whitewater boating of 3.5% (to $66.5 million) and commercial whitewater boating of 5.8% (to $270.2 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 1.5% (to $67.9 million) and commercial boating of 9.0%, (to $261.2 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 1.3% (to $68.0 million) and commercial boating of 11.3%, (to $254.4 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 2.3% (to $67.4 million) and commercial boating of 12.9%, (to $249.9 million) associated with changes in river conditions (highest impact of alternatives).	Compared to Alternative A, potential increase in use values for private whitewater boating of 0.4% (to $69.2 million) and decline for commercial boating of 2.3%, (to $280.2 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 0.6% (to $68.5 million) and commercial boating of 13.7%, (to $247.6 million) associated with changes in river conditions.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Use Values[a] (Cont.)							
Lower Grand Canyon	No change from current conditions in use values ($64.8 million) with no changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 2.0%, (to $3.6 million) for commercial 1-day boating of 4.6% (to $44.0 million); for overnight trips of 5.2% (to $0.52 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 3.4% (to $3.6 million), for commercial 1-day boating of 9.6% (to $41.7 million), for overnight trips of 11.5% (to $0.49 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 1.9% (to $3.8 million), decrease for commercial 1-day boating of 8.1% ($42.3 million), decrease for overnight trips of 11.7% (to $0.48 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 0.6% (to $3.7 million), decrease for commercial 1-day boating of 10.0% (to $41.5 million), decrease for overnight trips of 14.0% (to $0.47 million); no change commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 13.3% (to $4.2 million), decrease for commercial 1-day boating of 1.2% (to $45.5 million), decrease for overnight trips 8.9% ($0.46 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 6.8% (to $3.9 million), decrease for commercial 1-day boating of 8.0% (to $42.4) million); decrease for overnight trips of 13.2% (to $0.42 million); no change commercial flat-water boating ($14.5 million) associated with changes in river conditions.
Lake Mead	No changes from current conditions in use values ($9,114.5 million) with no change in water levels (highest impact of alternatives).	Same as Alternative A.	Compared to Alternative A, potential increase in use values of 0.3% (to $9,145.2 million) associated with higher water levels.	Compared to Alternative A, potential increase in use values of 0.3% (to $9,139.7 million) associated with higher water levels.	Compared to Alternative A, potential increase in use values of 0.3% (to $9143.5 million) associated with higher water levels.	Compared to Alternative A, potential increase in use values of 0.5% (to $9,157.5 million) associated with higher water levels (lowest impact of alternatives).	Compared to Alternative A, potential increase in use values of 0.3% (to 9,143.3 million) associated with higher water levels.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Non-Use Values							
Willingness to pay (national level)	No change in non-use values (highest impact of alternatives).	Compared to Alternative A, $1.5 billion increase.	Compared to Alternative A, $4.0 billion increase.	Compared to Alternative A, $4.5 billion increase (lowest impact of alternatives).	Compared to Alternative A, $4.0 billion increase.	Compared to Alternative A, $2.5 billion increase.	Compared to Alternative A, $3.5 billion increase.
Willingness to pay (regional level)	No change in non-use values (highest impact of alternatives).	Compared to Alternative A, $9 million increase.	Compared to Alternative A, $22 million increase.	Compared to Alternative A, $25 million increase (lowest impact of alternatives).	Compared to Alternative A, $23 million increase.	Compared to Alternative A, $11 million increase.	Compared to Alternative A, $19 million increase.
Economic Impacts[b]							
Lake Powell	No change in direct and indirect employment (2,444 jobs) and income ($99.7 million) (lowest impact of alternatives).	Same as Alternative A.	Compared to Alternative A, declines in direct and indirect employment (to 2,430 jobs) and income (to $99.1 million) of 0.6%.	Compared to Alternative A, declines in direct and indirect employment (to 2,435 jobs) and income (to $99.3 million) of 0.4%.	Compared to Alternative A, declines in direct and indirect employment (to 2,433 jobs) and income (to $99.2 million) of 0.5%.	Compared to Alternative A, declines in direct and indirect employment (to 2,418 jobs) and income (to $98.6 million) of 1.1% (highest impact of alternatives).	Compared to Alternative A, declines in direct and indirect employment (to 2,435 jobs) and income ($99.3 million) of 0.4%.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Glen Canyon, Upper and Lower Grand Canyon	No change in direct and indirect employment (156 jobs) and income ($3.6 million) associated with river-based recreational activities.	Same as Alternative A.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, egligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.
Lake Mead	No change in direct and indirect employment (5,099 jobs) and income ($208.0 million) (highest impact of alternatives).	Same as Alternative A.	Compared to Alternative A, increases in direct and indirect employment (to 5,116 jobs) and income (to $208.6 million) of 0.3%.	Compared to Alternative A, increases in direct and indirect employment (to 5,114 jobs) and income (to $208.6 million) of 0.3%.	Compared to Alternative A, increases in direct and indirect employment (to 5,115 jobs) and income (to $208.6 million) of 0.3%.	Compared to Alternative A, increases in direct and indirect employment (to 5,124 jobs) and income (to $209.0 million) of 0.5% (highest impact of alternatives).	Compared to Alternative A, increases in direct and indirect employment (to 5,115 jobs) and income (to $208.6 million) of 0.3%.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Economic Impacts*[b] *(Cont.)							
Seven-state region	No additional generation capacity construction and operation beyond existing capacity expansion plans, which would create 9,519 jobs and \$841.7 million in income during construction and 1,019 jobs and \$69.4 million in income during operation. No change in WAPA customer utility electricity rates (highest impact of alternatives).	Compared to Alternative A, no increases in WAPA customer utility generation capacity construction and operation direct and indirect employment and income impacts. Negligible decreases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 10,286 jobs) and income (to \$909.6 million) of 8.1%, and increases in operations employment (to 1,114 jobs) and income (to \$75.7 million) of 9.3%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income (lowest impact of alternatives).	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice							
Overall summary of environmental justice impacts	No change from current conditions. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and <1 year, respectively, of LTEMP period; financial impacts related to electricity sales similar to those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 6 years and 0–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 8 years and 2–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and 0–2 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	No impact; TMFs and mechanical removal not allowed under this alternative; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	Highest impact of all alternatives; TMFs and mechanical removal triggered in 11 years and 3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.
Tribal commercial and flat-water boating river boat rentals	No impacts expected with no changes in river visitation.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice (Cont.)							
Tribal retailing in vicinity of GCNRA and GCNP	No impacts expected with no changes in river visitation.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Tribal marina operators	No impacts expected.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, some impacts expected; decrease of 1.1% in visitation (highest impact of alternatives).	Same as Alternative A.
Access or damage to culturally important plants and resources	Negligible impacts.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, some damage and reduced access to resources; increase in visitor time off river (highest impact of alternatives).	Same as Alternative A.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice (Cont.)							
Effects on Tribal values associated with TMFs and mechanical extraction of trout in proximity to sacred places of emergence	Negligible impacts, with no TMFs and infrequent trout removal actions (in <1 year of LTEMP period).	TMFs and mechanical removal triggered in an average of 3 years and <1 year, respectively, of LTEMP period.	TMFs and mechanical removal triggered in an average of 6 years and 1 to 3 years, respectively, of LTEMP period.	TMFs and mechanical removal triggered in an average of 11.0 years and 2 years, respectively, of LTEMP period.	TMFs and mechanical removal triggered in an average of 3 years and 2 years, respectively, of LTEMP period.	No impact; TMFs and mechanical removal not allowed under this alternative (lowest impact of alternatives).	Highest impact of all alternatives; TMFs and mechanical removal triggered in an average of 11 years and 3 years, respectively, of LTEMP period (highest impact of alternatives).
Financial impacts on Tribes related to electricity sales	No impacts expected.	Impacts would be similar to those on non-Tribal customers and those under Alternative A (lowest impact of alternatives).	Impacts on Tribes would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts on Tribes would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts on Tribes would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts would be slightly higher (<$1.00/MWh) from those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A (highest impact of alternatives)	Impacts would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A

[a] Use values for alternatives are presented in Table 4.14-2.

[b] Employment and income values associated with recreational expenditures are presented in Tables 4.14-4 and 4.14-5, respectively. Employment and income associated with generation capacity are presented in Table 4.14-6, and residential electricity bills are presented in Table 4.14-7.

TABLE 4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP Alternatives[a]

	Mean Annual Net Economic Value ($ Million Net Present Value, 2015) for each Alternative						
Location and Activity	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Lake Powell							
General recreation	5,016.0	5,016.0	4,983.3	4,996.6	4,990.1	4,961.0	4,997.1
Glen Canyon							
Angling	20.1	19.4	18.9	19.2	19.4	17.4	18.9
Day-use rafting	48.7	48.7	48.7	48.7	48.7	48.7	48.7
Upper Grand Canyon							
Private whitewater boating	68.9	66.5	67.9	68.0	67.4	69.2	68.5
Commercial whitewater boating	286.9	270.2	261.2	254.4	249.9	280.2	247.6
Lower Grand Canyon							
Private whitewater boating	3.7	3.6	3.6	3.8	3.7	4.2	3.9
Commercial whitewater boating, 1-day trips	46.1	44.0	41.7	42.3	41.5	45.5	42.4
Commercial whitewater boating, overnight trips	0.55	0.52	0.49	0.48	0.47	0.46	0.42
Commercial flat-water boating	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Lake Mead							
General recreation	9,114.5	9,114.3	9,145.2	9,139.7	9,143.5	9,157.5	9,143.3
All activities	14,619.8	14,598.0	14,585.3	14,587.6	14,579.1	14,598.7	14,585.3

[a] Use values are based on historical direct natural flow hydrology, weighted by sediment flow condition.

Source: Gaston et al. (2014).

Alternative F and $14,579.1 million under Alternative E, the latter of which is a decline of 0.3% compared to Alternative A.

Mean annual use values for general recreation in Lake Powell would fall slightly from $5,016 million under Alternative A to between $4,997.1 million under Alternative G and $4,961.0 million under Alternative F the latter of which represents a decline of 1.1%. Potential declines in use values under each alternative would come primarily as a result of lower reservoir water levels, which would mean exposed beaches and mudflats, reducing the quality of the recreational experience. There would be no change in use values associated with Alternative B compared to Alternative A. For Lake Mead, general recreation use values would increase slightly, from $9,114.5 million under Alternative A to between $9,139.7 million under Alternative D to $9,157.5 million under Alternative F, the latter of which is an increase of 0.5%. Higher use values would primarily result from higher reservoir water levels covering previously exposed mudflats and beaches, improving the quality of the recreational experience. There would be a slight decrease in use values associated with Alternative B compared to Alternative A.

Although river-based recreation activities produce less mean annual use value than reservoir-based activities, there would be more variation among alternatives. Differences between each alternative and Alternative A, where high flow experiments are restricted, are primarily due to the extent to which larger fluctuations in flow associated with each alternative are shifted to seasons of the year that are more popular with visitors.

Angling use values in Glen Canyon would decline from $20.1 million under Alternative A to between $19.4 under Alternative E to $17.4 million under Alternative F, the latter representing a decline of 13.3%. Use values associated with commercial whitewater boating in the Upper Grand Canyon would fall from $286.9 million under Alternative A to between $280.2 million under Alternative F and $247.6 million under Alternative G, the latter representing a 13.7% decline. Mean annual use value generated by 1-day commercial whitewater boating trips in the Lower Grand Canyon would fall from $46.1 million under Alternative A to between $45.5 million under Alternative F and $41.5 million under Alternative E, the latter of which represents a decline of 10.0%.

Private whitewater boating in the Upper Grand Canyon produces $68.9 million in use values under Alternative A, values that would increase to $69.2 million under Alternatives F, an increase of 0.4%, and fall to between $68.5 million under Alternative G and $66.5 million under Alternative B, a decrease of 3.5%. Private whitewater boating in the Lower Grand Canyon would decrease from $3.7 million under Alternative A to $3.6 million for Alternative B and C, and increase to between $3.7 million under Alternative E, and $4.2 million under Alternative F, an increase of 13.3%,

Day-use rafting in Glen Canyon would generate $48.7 million in use value under each of the alternatives, commercial boating overnight trips would produce $0.5 million under each alternative, while commercial flat-water boating in the Lower Grand Canyon would produce $14.5 million under each alternative. Use values for either activity would not change under any of the alternatives, because demand for these activities would not be affected by river levels or fluctuations in river flow.

With the exception of changes in use value associated with commercial whitewater overnight boating trips and commercial flat-water boating in the Lower Grand Canyon, changes in use value for all other forms of river recreation were statistically significant at the 90% confidence level under each alternative, while changes in use value associated with reservoir recreation were not statistically significant under any of the alternatives.

4.14.2.2 Environmental Non-Use Values

NPS conducted a survey to determine non-use values associated with the impacts of Glen Canyon Dam operations on the endangered humpback chub, sandbars in the Grand Canyon, populations of large trout in Glen Canyon, and hydropower (Neher et al. 2016). The survey used a discrete choice model to estimate household and aggregate willingness to pay for various environmental outcomes associated with operations. These outcomes were then mapped to specific LTEMP alternatives to determine willingness to pay for each alternative. These outcome results were based on the primary modeling metrics used in the LTEMP EIS for these resource areas. For sediment, the metric used was the sand load index. For humpback chub, the metric used was from the coupled rainbow trout–humpback chub model. For the purposes of this quantative study, the simplication of using these main modeling metrics was necessary; however, additional quantitative and qualitative analyses are fully discussed in the LTEMP EIS Sections 4.3 and 4.5. It should also be noted that the survey respondents seemed to value the status quo for trout populations most highly and provided no solid trend regarding increasing trout populations; therefore the trout results were deemed inconclusive and not used for the final outcomes listed below.

Survey data were collected from two samples of households, a national sample including all U.S. households, and a regional sample including a sample of households purchasing power from Glen Canyon Dam, and including all utilities receiving power from the Glen Canyon Dam.

The results from the national and regional samples indicated that, based on the estimated willingness to pay for environmental outcomes, Alternative D (the preferred alternative) would be the most highly valued of the alternatives with an aggregate annual willingness to pay value of $4,486 million, and a regional aggregate annual value of $25 million (Table 4.14-1) (Neher et al. 2016). The next highest rated alternatives were Alternatives C and E. Alternative B was associated with the lowest willingness to pay value based on expected outcomes.

A recently published study (Jones et al. 2016) offers an alternative total economic value analysis to that presented by Neher et al. (2016). The Jones et al. analysis relied on the contingent valuation methodology, which is similar to the methodology used by Welsh et al. (1995), but different from the methodology used by Neher et al. The Neher et al. analysis relied on the choice experiment methodology, which incorporates recent methodological advances in non-market valuation. However, the Jones et al. analysis is also different from the Neher et al. analysis because it included two additional attributes: (1) impacts on Tribes and rural western communities that depend on hydroelectric production, and (2) increases in air pollution by switching to nonrenewable fossil fuels in the power generation system. The Jones et al. study concluded that including these additional attributes would “significantly decrease willingness to pay for changing Glen Canyon Dam operations, and demonstrate a significant fraction of the population with a positive willingness to pay for maintaining dam operations at current levels."

The Jones et al. (2016) study was a pilot study that relied on an internet panel rather than a randomized mail survey; the Tribe and rural western community attributes did not identify specific causal relationships or quantified values to ensure consistent respondent interpretation, and potential air quality impacts associated with increased fossil fuel use may be overstated for the range of alternatives analyzed for LTEMP (see Sections 4.15 and 4.16). While this study created a new framework that provided a different way of evaluating some of the attributes that would not have been analyzed otherwise, the issues discussed above limit the application of this study to the LTEMP EIS.

4.14.2.3 Recreational Economic Impacts

The regional economic impacts of recreation in Lake Powell, Lake Mead, and the Grand Canyon are closely tied to visitation levels for each recreational activity. By far the most significant recreational resource is Lake Mead, which drew almost 6 million individual trips in 2012, 72.0% of the total number of trips to these areas (Table 4.14-3). Lake Powell drew 1.9 million trips, or 23.0% of the total, while there were 0.2 million individual Grand Canyon river trips in 2012 (2.5% of the total). Of the river-based recreational activities, commercial flat-water boating in the Lower Grand Canyon, below Diamond Creek, drew the largest number of individual trips (95,520 individual trips, or 46.0% of the total number of individual river trips), followed by day-use rafting in Glen Canyon (53,578 individual trips, 25.8% of the total) and 1-day white water boating below Diamond Creek (28,748 individual trips, 13.8% of the total). Commercial whitewater boating in the Upper Grand Canyon drew 17,384 individual trips, or 8.4% of total river trips.

Recreational expenditures by visitors to Lake Powell and Lake Mead, and to the Upper and Lower Grand Canyon, create substantial employment and income in the six-county area in Arizona and Utah (Tables 4.14-4 and 4.14-5). Boating in Lake Mead currently produces 5,099 total (direct and indirect) jobs and $208 million in total income (direct and indirect) annually; boating on Lake Powell produces 2,444 total jobs and $99.7 million in income. Over the 20-year LTEMP period, annual direct and indirect economic activity would fall to between 2,435 jobs and $99.3 million in income for Alternative G and 2,418 jobs and $98.6 million in income for Alternative F, for Lake Powell, with increases of between 5,115 jobs and $208.6 million in income for Alternative G, and 5,124 jobs and $209.0 million in income for Alternative F for Lake Mead. Changes in employment under Alternative F resulting from changes in recreation at Lake Powell would represent a decrease of 1.1% in compared to Alternative A, and an increase of 0.5% under Alternative F at Lake Mead. There would be no change in recreational economic impacts associated with Alternative B compared to Alternative A.

Because current NPS regulations restrict the number of river boating trips that can be taken, and demand consistently exceeds the number of available permits (Gaston et al. 2014), the analysis assumes that the number of whitewater boating trips would not change as a result of any

TABLE 4.14-3 Recreational Visitation by Activity in Lake Powell, Upper and Lower Grand Canyon, and Lake Mead, 2012

Location	Activity	Number of Annual Individual Trips
Lake Powell	General recreation	1,914,768
Glen Canyon	Angling	4,925
	Day-use rafting	53,578
Upper Grand Canyon	Private white water boating	5,978
	Commercial white water boating	17,384
Lower Grand Canyon	Private white water boating	1,445
	Commercial white water boating, one-day trips	28,748
	Commercial white water boating, overnight trips	100
	Commercial flat-water boating	95,520
Lake Mead	General recreation	5,991,767
Total	All activities	8,114,213

Source: Gaston et al. (2014).

TABLE 4.14-4 Mean Annual Employment Associated with Recreational Expenditures under LTEMP Alternatives

	Annual Employment (Number of Full-Time Equivalent Jobs[a]) under LTEMP Alternatives						
Location and Activity	A	B	C	D	E	F	G
Lake Powell							
General Recreation	2,444	2,444	2,430	2,435	2,433	2,418	2,435
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	156	156	156	156	156	156	156
Lake Mead							
General Recreation	5,099	5,099	5,116	5,114	5,115	5,124	5,115
Total							
All Activities	7,699	7,699	7,700	7,704	7,702	7,697	7,706

[a] To accurately estimate employment, which may include part-time or overtime working, full-time equivalent (FTE) jobs are used. These are the total number of hours worked in a particular activity divided by the number of regular working hours in a year.

Source: IMPLAN Group, LLC (2014).

TABLE 4.14-5 Mean Annual Income Associated with Recreational Expenditures under LTEMP Alternatives

	Annual Income ($million, 2013) under LTEMP Alternatives						
Location and Activity	A	B	C	D	E	F	G
Lake Powell							
General Recreation	99.7	99.7	99.1	99.3	99.2	98.6	99.3
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Lake Mead							
General Recreation	208.0	208.0	208.6	208.6	208.6	209.0	208.6
Total							
All Activities	311.3	311.3	311.3	311.5	311.4	311.2	311.6

Source: IMPLAN Group, LLC (2014).

of the alternatives, meaning that the regional economic impacts for river recreation under each of the alternatives would be the same as for Alternative A.

Angling trips could be affected under each of the alternatives, especially if HFEs occur during prime fishing months. High flows would mean poor fishing conditions, limited or no beach or shoreline access, and no wading; these restrictions and limitations could affect annual visitor spending (including spending on lodging, boat fuel, groceries, guide fees, and fishing licenses) and consequently could affect the regional economy. The number of HFEs would vary among alternatives, and would range from 5.5 under Alternative A to 38.1 under Alternative F (Alternative D would have an average of 21.1 HFEs).[35] The maximum number of days HFEs would disrupt angling in any year would range from 4 under Alternative B to 18 under Alternative G; Alternative G is highest because it includes the potential for extended-duration HFEs up to 14 days long (the maximum number of HFE days within a calendar under Alternative D would be 14 days). Note that extended-duration HFEs are expected to be triggered relatively infrequently and would be limited to no more than four under Alternative D (see Section 4.3.3). Although the variation in HFE frequency and duration would mean larger impacts under Alternatives D and G, because of the relatively small number of HFE days, and the timing of the proposed HFEs compared to that of the majority of angler trips, the overall economic impact of HFEs on angling and on the regional economy would be negligible, with less than one job and less than $20,000 in income lost annually in the six-county area.

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[35] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs is not expected to result in a change in Alternative D's impacts on socioeconomics.

Similarly, although the impacts of HFEs on license revenues would be slightly larger under Alternatives D and G, as would the economic impact of the spending of these revenues, the economic impacts are expected to be negligible for all alternatives, less than one job and $2,500 annually in income in the six-county area.

The largest river recreation impacts are from 1-day commercial whitewater boating trips below Diamond Creek, which produces 61 jobs annually and $1.4 million in income, and commercial whitewater trips in the Upper Grand Canyon (37 jobs and $0.8 million in income). Angling (19 jobs and $0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water boating) (19 jobs and $0.4 million in income) below Diamond Creek would produce smaller impacts. A total of 156 jobs and $3.6 million in income are currently produced annually across all river recreational activities under Alternative A, with the same annual impacts expected under each alternative.

4.14.2.4 Customer Utility Electricity Generation Capacity and Residential Rate Increase Impacts

Although there would be no change in Glen Canyon Dam capacity under Alternative A, forecasted increases in the demand for electricity and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built by the eight largest WAPA customer utilities under Alternative A over the 20-year study period. Under Alternative B, 4,820 MW of additional capacity would also be added, while a reduction in available generating capacity at Glen Canyon Dam under Alternatives C, D, E, and G would mean that alternative generating capacity would be required by WAPA customer utilities to replace lost hydropower capacity. An additional 5,050 MW would be required under Alternatives C, D, E, and G (an increase of 4.8% compared to Alternative A), with 5,280 MW needed under Alternative F (an increase of 9.5%) (see Section 4.13.2.3).

Using estimated capital and operating costs associated with providing additional capacity under each alternative for the eight largest WAPA customer utilities, the economic impacts of construction and operation of additional capacity are shown in Table 4.14-6. Under Alternative A, powerplant construction would produce an estimated 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants under Alternative A would create 1,019 total jobs and $69.4 million in annual earnings. Alternative B would also require the same capacity as Alternative A, with 9,519 jobs and $841.7 million in earnings created directly and indirectly in the seven states. Operations would produce 1,019 total jobs and $69.4 in earnings per year. Alternatives C, D, E, and G would require slightly more additional capacity than Alternative A, producing 9,895 total construction and 1,065 total operations jobs, an increase of 3.9%, $875.3 million in construction earnings, and $72.5 annually during operations. The largest impacts of capacity additions would be under Alternative F, where 10,286 total jobs, an increase of 8.1%, and $909.6 million in earnings would be produced during construction, and 1,114 jobs and $75.7 million would be produced annually in earnings during operations. It should be noted that the alternatives could affect the seasonal pattern of Lake Mead elevations and, thus, power generation and capacity at

TABLE 4.14-6 Seven-State Economic Impacts[a] under LTEMP Alternatives of Additional Generating Capacity for the Eight Largest Customer Utilities, 2015–2033

	Alternative						
Parameter	A	B	C	D	E	F	G
Construction							
Employment (FTEs)	9,519	9,519	9,895	9,895	9,895	10,286	9,895
Earnings ($Million 2015)	841.7	841.7	875.3	875.3	875.3	909.6	875.3
Operations							
Employment (FTEs)	1,019	1,019	1,065	1,065	1,065	1,114	1,065
Earnings ($Million 2015)	69.4	69.4	72.5	72.5	72.5	75.7	72.5

[a] Impacts assume average hydrological conditions, and that powerplants would use advanced oil/gas combined cycle or advanced combustion turbine technology. Construction impacts are total impacts over a 3-year construction period; operations impacts are average annual impacts.

Source: IMPLAN Group, LLC (2014).

Hoover Dam, and the associated impacts described here for Glen Canyon Dam. However, such effects related to Hoover Dam generation are anticipated to be relatively small (Section 4.13).

Costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently, changes in the electric bills of residential customers. Although there is considerable variation in the amount of power sold by WAPA to customer utilities, ranging from 0.8% of customer utility power sales with Salt River Project to 23.7% with Navajo Tribal Utility Authority among the eight largest customer utilities, only 7.3% of power sales for all eight of the largest customer utilities comes from WAPA, meaning that the cost of additional capacity required under each alternative to replace capacity lost at Glen Canyon Dam has only negligible impacts (average less than 2% in maximum impacts year) on electric bills paid by residential customers of the eight largest WAPA customer utilities. Two groups of utilities that are allocated a large fraction of their generation resources from SLCA/IP projects are Tribal utilities and other small utilities. These groups would be affected more by capacity expansion differences among alternatives than others; Tribal utilities (Navajo and Cocopah) would experience up to a 2.8% increase in retail rates, while small utilities with the largest impact would experience up to a 3.1% increase in retail rates (see Appendix K for additional detail).

Although the economic impacts of changes in retail electricity rates and the corresponding impacts on residential customer bills would be dependent on the timing and magnitude of capacity expansion required under each alternative, changes in customer rates under each alternative are small. Table 4.14-7 shows the average annual losses in economic activity in the seven-state region for the eight largest customer utilities. Impact data are based on the aggregation of bill increases across the eight largest customer utilities, weighting by

TABLE 4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to Alternative A

	Alternative					
Parameter	B	C	D	E	F	G
Changes to employment (FTE jobs) compared to Alternative A	An increase in up to 10 new jobs	A reduction of 23 jobs	A reduction of 10 jobs	A reduction of 10 jobs	A reduction of 41 jobs	A reduction of 25 jobs
Changes to earnings (in millions of 2015 dollars) compared to Alternative A	An increase of $0.1 in earnings	A loss of $1.0 in earnings	A loss of $0.4 in earnings	A loss of $0.3 in earnings	A loss of $1.9 in earnings	A loss of $1.2 in earnings

Source: IMPLAN Group, LLC (2014).

individual utility power sales compared to total power sales for all eight utilities. Changes in retail rates range from a decrease of 0.27%% under Alternative B to an increase of 1.21% under Alternative F (Table 4.13-1).

The impact of these increases on employment and income in the seven-state region would range from less than 10 total (direct and indirect) jobs lost and $0.3 million in earnings lost under Alternative E to 41 jobs and $1.9 million in earnings lost under Alternative F. A slight decrease in electric bills under Alternative B would mean small increases in employment (less than 10 jobs) and earnings (an increase of $0.1 million).

4.14.2.5 Environmental Justice Impacts

Changes in river and reservoir recreational visitation might disproportionately impact low-income and minority populations including Tribal communities, both in the counties in the vicinity of the GCNRA and GCNP, and in the seven-state area in which power from Glen Canyon Dam is marketed.

Eleven-County Region

There were a large number of low-income and minority individuals in the 11-county region as a whole in the 2010 Census, with 38.0% of the population classified as minority, and 12.7% classified as low-income using data from the 2008–2012 American Community Survey. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in a state, for example), rather than only on the number of minority and low-income *individuals* present in a geographic area. The number of minority or low-income individuals does not exceed state averages by 20 percentage points or more, and does not exceed 50% of the total population in the area. This means that for the 11-county region as a whole, there are no minority or low-income populations based on the 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. The number of minority individuals exceeds the state average by 20 percentage points or more in Apache County, Arizona; McKinley County, New Mexico; and San Juan County, Utah. Minority individuals exceed 50% of the total population in Apache County and Navajo County, Arizona; Cibola County, McKinley County, and San Juan County, New Mexico; and in San Juan County, Utah, indicating that there are minority populations in each of these counties based on county level data in the 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. Because the number of low-income individuals does not exceed the state average by more than 20 percentage points, or does not exceed 50% of the total population in any of the 11 counties, there are no low-income populations based on county-level data in the 11-county region.

A large number of census block groups in the vicinity of the GCNRA and GCNP with low-income and minority populations could be affected if changes in visitation levels produced impacts that were high and adverse. In Coconino County, Arizona, a number of block groups have populations where the percentage of minorities is more than 20 percentage points higher than the state average. These are located in the eastern part of the county on the Navajo Nation Indian Reservation and Hopi Indian Reservation, in the western part of the county, including the Havasupai Indian Reservation and the Hualapai Indian Reservation, which are also located in one block group in eastern Mohave County, Arizona. One census block group in Page, Arizona, also has a minority population which is more than 50% of the total. There are a number of census block groups in San Juan County, Utah, where more than 50% of the total population is minority. These are located in the southern portion of the county and include the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation.

There are a large number of census block groups in the vicinity of GCNRA and GCNP where the percentage of low-income individuals is more than 20 percentage points higher than the state average. These are located in (1) Coconino County, Arizona, on the Navajo Nation Indian Reservation and the Hopi Indian Reservation; (2) Navajo County, Arizona, on the Navajo Nation Indian Reservation, which also contains the Fort Apache Indian Reservation; (3) eastern Mohave County, Arizona, on the Hualapai Indian Reservation; and (4) southeastern and southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation. There are also a number of census block groups in the 11-county area where more than 50% of the total population is below the poverty level. These are located in (1) the eastern part of Coconino County, Arizona, on the Navajo Nation Indian Reservation and Hopi Indian Reservation; (2) southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; (3) the northern parts of Navajo County and Apache County, Arizona; and (4) southwestern Navajo County on the Fort Apache Indian Reservation.

Changes to river recreation could impact Tribes in the vicinity of GCNRA and GCNP. Commercial whitewater and flat-water boating below Diamond Creek is important to the Hualapai Tribe, for employment and income, but as Table 4.14-5 shows, there are negligible differences expected among the alternatives. NPS regulates the number of river boating trips that can be taken, with a set number of river trip launches per year, meaning that none of the alternatives are expected to impact overall levels of recreational river visitation. Although differences in time off river for river trips among the alternatives, or differences in stage levels, could change visitation patterns, either of these leading to potential damage and reduced access to culturally important plants and resources, these impacts are expect to be negligible for all alternatives except Alternative F, which may have a slight increase in the potential for effects to cultural sites based on more time off river (see Table 4.14-5). Changes to river stage levels, such as those caused by HFEs, could temporarily restrict Tribal access to culturally important resources, such as springs, minerals, and plants. Similar impacts may also occur if recreational visitors spend more time away from destination campsites with inundation by higher water levels (Section 4.8), but these impacts are expected to be small. Higher water levels may have positive impacts from flushing out springs that have cultural significance to Tribal members, such as Pumpkin Springs (Section 4.9).

Temporary changes in access to culturally important Tribal resources and other areas of significance to tribes may also impact Tribal members. As described in Section 4.9, for those Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements without which its sacredness would not be complete. The Zuni, in particular, have established a lasting familial relationship with all aquatic life in the Colorado River and the other water sources in the Canyons (Dongoske 2011a). They consider the taking of life through the mechanical removal of trout or TMFs to be offensive, and to have dangerous consequences for the Zuni. The confluence of the Colorado River and the Little Colorado River is considered a sacred area because of its proximity to places identified in traditional Tribal narratives as the locations of the Zuni and the Hopi emergence into this world and other important events. The killing of fish in proximity to sacred places of emergence is considered desecration, and would have an adverse effect on the Grand Canyon as a Zuni Traditional Cultural Property. The Zuni have expressed their view on this subject in Section 3.9.6. As shown in Table 4.14-1, there are differences among alternatives in the frequency of TMFs and mechanical removal of trout; Alternatives A and F would have the fewest of these actions, and Alternatives D and G the most.

In addition, fluctuations in reservoir levels could impact Tribes and resources managed by them, such as the Navajo Antelope Point marina operations. As shown in Section 4.8, there are negligible differences among all alternatives for impact to the Antelope Point marina, except under Alternative F, which shows a small difference from Alternative A (1.1%). As presented in Table 4.8-3, impacts on tradespeople making and selling jewelry and souvenirs to the traveling public along various routes in the region, primarily those in the vicinity of GCNRA and GCNP, are likely to be negligible, with no differences between the alternatives.

Seven-State Region

A large number of minority and low-income individuals are located in the seven-state region in which electricity from Glen Canyon Dam is marketed. In the region as whole, 35.7% of the population is classified as minority, while 15.1% is classified as low income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in the nation, for example), rather than only on the number of minority and low-income *individuals* present in a geographic area. The number of minority or low-income individuals does not exceed the respective national averages by 20 percentage points or more, and does not exceed 50% of the total population in the area, meaning that for the seven-state region as a whole, there are no minority or low-income populations based on 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. Within one state in the region, New Mexico, 59.5% of the total population is minority, meaning that according to 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines, there is a minority population in the state.

Although there are no minority populations in any of the seven states except for New Mexico, and no low-income populations, there are a large number of Tribal members in the seven-state area, many of whom reside on Indian Reservations. Many of these individuals have low-income status.

Tribal members receive a significant portion of their electricity from WAPA, which currently targets an allocation of 65% of total Tribal electrical use to the 57 Tribes or Tribal entities currently receiving an allocation of power from SLCA/IP; this includes power from Glen Canyon Dam (see Section K.4 in Appendix K). Nine Tribes operate their own electric utilities and receive power directly from WAPA; the remaining 48 have a benefit crediting arrangement. In a benefit crediting arrangement, the Tribe's electric service supplier takes delivery of the SLCA/IP allocation and in return gives an economic benefit or a payment to the tribe.

Tribes may be financially affected in one of three ways by the LTEMP alternatives: (1) a change in the rate they pay for SLCA/IP electric power if they operate their own utility; (2) a change in the payment they receive from their electric service provider if they have a benefit crediting arrangement; or (3) a change in both the payment they receive from their supplier for the benefit crediting arrangement and the electric rate their supplier charges if their supplier also receives an SLCA/IP allocation.

The benefit credit is computed by taking the difference between the SLCA/IP rate and the supplier rate and multiplying it by the Tribe's SLCA/IP allocation. Because the SLCA/IP rate is generally lower than the supplier's rate, the difference between the rates is considered a benefit by the Tribe and is the financial equivalent of a direct delivery of electricity.

Tribes whose supplier also receives a SLCA/IP allocation have a second financial impact. The retail electricity rate their supplier charges could change as a result of an alternative. The retail rate impact is computed by taking the difference in retail rates between an alternative and Alternative A and multiplying by the total electrical use on the Tribe's reservation. Therefore, the financial impact on these Tribes is the sum of the Tribal benefit credit and the retail rate impact.

The financial impact of all alternatives would be relatively small, but the impact on Tribal members would be greater than on non-Tribal residential customers (Table 4.14-8; see Section K.4 in Appendix K for a description of the analysis and results). Differences in impacts on the three groups are as follows:

- Tribal customers receiving power from a non-Tribal utility with an associated benefit credit: Financial impacts (increases in retail rates and reductions in benefit credit) would range from an average increase (compared to Alternative A) of $0.00/MWh under Alternative B to $1.63/MWh under Alternative G. Alternatives C, D, E, and F would produce an increase in financial impact of $0.37, $0.31, $0.24, and $1.53/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of –$0.05 (net benefit), $0.91, $0.68, $0.58, $3.26, and $2.84/MWh under Alternatives B, C, D, E, F, and G, respectively.

- Tribal customers that purchase from Tribal-owned utilities: Financial impacts (increases in retail rates) would range from an average increase (compared to Alternative A) of $0.00/MWh under Alternative B to $1.72/MWh under Alternative G. Alternatives C, D, E, and F would produce an increase in financial impact of $0.37, $0.31, $0.24, and $1.53/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of $0.02, $0.44, $0.39, $0.30, $2.00, and $2.37/MWh under Alternatives B, C, D, E, F, and G, respectively.

- Non-Tribal customers: Financial impacts (increases in retail rates) would range from an average increase (compared to Alternative A) of –$0.02/MWh (net benefit) under Alternative B to a $0.67/MWh increase under Alternative F. Alternatives C, D, E, and G would produce an increase in financial impact of $0.22, $0.15, $0.13, and $0.38/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of –$0.07 (net benefit), $0.62, $0.41, $0.38, $1.86, and $1.07/MWh under Alternatives B, C, D, E, F, and G, respectively.

In summary, for the majority of resource areas, impacts on minority and low-income individuals are likely to be negligible. Commercial whitewater and flat-water boating below Diamond Creek is important to the Hualapai Tribe for employment and income, but there are expected to be negligible economic differences expected among the alternatives. Fluctuations in reservoir levels affecting the Navajo Antelope Point marina operations are expected to be negligible under all alternatives except Alternative F, which shows a small difference from Alternative A. Impacts also are likely to be negligible on tradespeople making and selling jewelry and souvenirs to the traveling public along routes in the vicinity of the Grand Canyon itself, with no differences between the alternatives.

TABLE 4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers

Parameter	Average Value under Alternative A ($/MWh)	Change from Alternative A: Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Tribal Customers with Benefit Credit (48 Utilities)							
Average Retail Rate ($/MWh)	91.82	–0.01	0.08	0.05	0.05	0.23	0.13
Average Benefit Credit ($/MWh)	8.84	–0.01	–0.27	–0.24	–0.18	–1.23	–1.45
Total of Retail and Benefit Impacts ($/MWh)	82.98	0.00	0.37	0.31	0.24	1.53	1.63
Maximum Impact: Hopi Tribe	72.67	–0.05	0.91	0.68	0.58	3.26	2.84
Tribal Customers without Benefit Credit (nine Utilities)							
Average Retail Rate ($/MWh)	95.09	0.00	0.40	0.33	0.26	1.63	1.72
Maximum Impact: Ak-Chin Indian Community	83.10	0.02	0.44	0.39	0.30	2.00	2.37
Non-Tribal Customers (142 Utilities)							
Average Retail Rate ($/MWh)	92.15	–0.02	0.22	0.15	0.13	0.67	0.38
Maximum Impact	73.74	–0.07	0.62	0.41	0.38	1.86	1.07

Differences in time off river and differences in stage levels, such as those caused by inundation during HFEs, could lead to damage and reduced Tribal access to culturally important plants and resources. However, the impacts are expected to be negligible for all alternatives except Alternative F, which may lead to a slight increase in impacts on cultural sites.

The financial impacts on Tribal members would be greater than those on non-Tribal residential customers, especially under Alternatives F and G. Financial impacts of other alternatives are all less than $1.00/MWh.

4.14.3 Alternative-Specific Impacts

4.14.3.1 Alternative A (No Action Alternative)

Use values associated with recreation in Lake Powell, Lake Mead, and the Upper and Lower Grand Canyon are substantial and current use values would not change under Alternative A. Use values associated with general recreational activities in Lake Mead ($9,114.4 million) and Lake Powell ($5,016 million) constitute almost 97% of the value created by reservoir and river resources in the affected area under Alternative A. Under Alternative A, commercial and private whitewater boating would produce $286.9 million and $68.9 million in use value, respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

There would be no change in the estimated per-household willingness to pay values associated with the impact of dam operations under Alternative A on humpback chub populations and sandbars in the Grand Canyon.

Recreational expenditures by visitors to Lake Powell, Lake Mead, and the Upper and Lower Grand Canyon create substantial employment and income in the six-county area in Arizona and Utah. Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and the largest amount of income, amounting to 7,543 jobs and $307.7 million in income annually over the 20-year LTEMP period.

The largest river recreation impacts are from 1-day commercial whitewater boating trips below Diamond Creek, which produces 61 jobs and $1.4 million in income, and commercial whitewater trips in the Upper Grand Canyon (37 jobs and $0.8 million in income). Angling (19 jobs and $0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water boating) (19 jobs and $0.4 million in income) below Diamond Creek would produce smaller impacts.

A total of 7,699 jobs and $311.3 million in income would be produced annually across all reservoir and river recreational activities under Alternative A over the 20-year LTEMP period.

Under Alternative A, there would be an estimated average 5.5 HFEs over the LTEMP period and a maximum of 8 HFE days in a calendar year; there would be no HFEs after 2020. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Although no additional generating capacity would be required under Alternative A as a result of changes in Glen Canyon Dam operations among the eight largest WAPA customer utilities, forecasted increases in the demand for electricity in the service territories of the eight largest customer utilities and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built under Alternative A over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants with Alternative A would create 1,019 total jobs and $69.4 million in annual earnings associated with new jobs.

Because there would be no change in Glen Canyon Dam operations as a result of Alternative A, there would be no impact on retail rates charged by the eight largest WAPA customer utilities or the electric bills paid by their residential customers, or subsequent impacts on employment or income, in the seven-state region.

In summary, with no change in reservoir levels or river conditions under Alternative A, there would be no change from current conditions in use values, economic activity, residential electricity bills, or environmental justice.

4.14.3.2 Alternative B

Under Alternative B, total use values associated with recreation in Lake Mead and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while remaining unchanged for Lake Powell (Table 4.14-2). General recreational activities in Lake Mead would produce $9,114.3 million in use value and $5,016.0 million at Lake Powell, while commercial and private whitewater boating would produce $270.2 million (5.8% decrease) and slightly less than $66.5 million (3.5% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative B on humpback chub populations and sandbars in the Grand Canyon are estimated to be $1.5 billion at the national level and $9 million at the local (eight-county) level.

Under Alternative B, recreational expenditures by visitors and the number of jobs and income that would be created would be the same as under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,543 jobs and $307.7 million in income annually over the 20-year LTEMP period. Impacts on river-based recreational activities would be the same as those under Alternative A.

Under Alternative B, there would be an estimated average 7.2 HFEs over the LTEMP period and a maximum of 4 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Because Alternative B would feature the same monthly volumes as Alternative A, there would be no change in use value and economic impact associated with reservoir-based recreational activities. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily due to larger fluctuations in flow that would occur in seasons of the year more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative B compared to Alternative A.

Although additional generating capacity would not be necessary under Alternative B as a result of changes in Glen Canyon Dam operations among the eight largest WAPA customer utilities, forecasted increases in the demand for electricity in the service territories of the eight largest customer utilities and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built under Alternative B over the 20-year LTEMP period, as would be the case for Alternative A. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants under Alternative B would create 1,019 total jobs and $69.4 million in annual earnings associated with new jobs.

Because there would be slightly more Glen Canyon Dam generation capacity under Alternative B, retail rates charged by the eight largest WAPA customer utilities and the electric bills paid by their residential customers would fall, meaning the addition of less than 10 total (direct and indirect) jobs and an increase of $0.1 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative B, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to implementation of TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be similar to those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative B, there would be a decline in use values associated with Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, Lower Grand Canyon private whitewater boating commercial whitewater 1-day trips, and Lake Mead recreation compared to Alternative A. There would be no change in use values associated with Lake Powell recreation, Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with Lake Powell and Lake Mead recreation, or river recreation. There would be an increase in economic activity as a result of lower residential electric bills compared to Alternative A.

4.14.3.3 Alternative C

Under Alternative C, total use values associated with recreation in Lake Powell and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities would produce $9,145.2 million (0.3% increase) in use value at Lake Mead and $4,983.3 million (0.7% decrease) at Lake Powell, while commercial and private whitewater boating would produce $261.2 million (9.0% decrease) and $67.9 million (1.5% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative C on humpback chub populations and sandbars in the Grand Canyon are estimated to be $4.0 billion at the national level and $22 million at the local (eight-county) level.

Under Alternative C, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,544 jobs and $307.7 million in income annually over the 20-year LTEMP period, a difference of 0.04% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,700 jobs and $311.3 million in income would be produced annually across all reservoir and river recreational activities under Alternative C over the 20-year LTEMP period.

Under Alternative C, there would be an estimated average 21.3 HFEs over the LTEMP period and a maximum of 10 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Differences in use value and economic impact associated with reservoir-based recreational activities under Alternative C compared to Alternative A would result primarily from changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience, and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily due to the shifting of monthly volumes away from seasons of the year that are more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative C compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative C, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities, and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative C over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, and $875.3 million in earnings. Operation of new powerplants under Alternative C would create 1,065 total jobs, a difference of 3.9% compared to Alternative A, and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative C would only have negligible impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities, and would mean the loss of 23 total (direct and indirect) jobs and $1.0 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative C there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, Lower Grand Canyon private whitewater boating, and commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values and economic activity associated with Lake Mead recreation. Increased economic activity would result from customer utility capacity expansion compared to Alternative A, and reduced economic activity would come as a result of higher residential electric bills.

4.14.3.4 Alternative D (Preferred Alternative)[36]

Under Alternative D, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,139.7 million (0.3% increase) in use value and $4,996.6 million (0.4% decrease) at Lake Powell, while commercial and private whitewater boating would produce $254.4 million (11.3% decrease) $68.0 million (a 1.3% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative D on humpback chub populations and sandbars in the Grand Canyon are estimated to be $4.5 billion at the national level and $25 million at the local (eight-county) level. These are the highest values of any alternative.

Under Alternative D, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and $307.8 million in income annually over the 20-year study period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those for Alternative A. A total of 7,702 jobs and $311.4 million in income would be produced annually across all reservoir and river recreational activities under Alternative D over the 20-year LTEMP period.

Under Alternative D, there would be an estimated average 21.1 HFEs over the LTEMP period and a maximum of 14 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative D compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience, as well as reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the shifting of monthly volumes away from seasons of the year more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative D compared to Alternative A.

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[36] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on socioeconomic or environjmental justice impacts.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative D, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative D over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings. Operation of new powerplants under Alternative D would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative D would have impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities and would mean the loss of less than 10 total (direct and indirect) jobs and $0.4 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators or Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative D there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values for Lower Grand Canyon private whitewater boating and use values and economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.5 Alternative E

Under Alternative E, total use values associated with recreation in Lake Powell and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,143.5 million (0.3% increase) in use value and $4,990.1 million (0.5% decrease) at

Lake Powell, while commercial and private whitewater boating would produce $249.9 million (12.9% decrease) and $67.4 million (a 2.3% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative E on humpback chub populations and sandbars in the Grand Canyon are estimated to be $4.0 billion at the national level and $23 million at the local (eight-county) level.

Under the Alternative E, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and $307.8 million in income annually over the 20-year study period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,702 jobs and $311.4 million in income would be produced annually across all reservoir and river recreational activities under Alternative E over the 20-year LTEMP period.

Under Alternative E, there would be an estimated average 17.1 HFEs over the LTEMP period and a maximum of 8 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Small reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative E compared to Alternative A would result primarily from changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the shifting of monthly volumes away from seasons of the year that are more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative E compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative E, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative E over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings.

Operation of new powerplants under Alternative E would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative E would only have negligible impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities, and would mean the loss of less than 10 total (direct and indirect) jobs and $0.3 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative E, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative E there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon private whitewater boating, commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values and economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.6 Alternative F

Under Alternative F, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,157.5 million (0.5% increase) in use value and $4,961.0 million (1.1% decrease) at Lake Powell, while commercial and private whitewater boating in the Upper Grand Canyon would produce $280.2 million (2.3% decrease) and $69.2 million (0.4% increase), respectively; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative F on humpback chub populations and sandbars in the Grand Canyon are estimated to be $2.4 billion at the national level and $11 million at the local (eight-county) level.

Under Alternative F, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,542 jobs and $307.6 million in income annually over the 20-year LTEMP period, a difference of 0.02% compared to Alternative A. Impacts on the various river-based recreational activities would be the same as those under Alternative A. A total of 7,697 jobs and $311.2 million in income would be produced annually across all reservoir and river recreational activities under Alternative F over the 20-year LTEMP period.

Under Alternative F, there would be an estimated average 38.1 HFEs over the LTEMP period and a maximum of 8 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Small reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative F compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the large shifts in monthly volumes; although the high volumes of May and June would result in higher use value during those months, the very low flows for much of the rest of the year would result in lower use value at those times. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative F compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative F, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities, and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,280 MW of new capacity would be built under Alternative F over the 20-year study period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 10,286 total (direct and indirect) jobs in the seven-state region, a difference of 8.1% compared to Alternative A, and $909.6 million in earnings. Operation of new powerplants under Alternative F would create 1,114 total jobs and $75.7 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative F would only have negligible impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities, and would mean the loss of 41 total (direct and indirect) jobs and $1.9 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative F, although changes in reservoir visitation would be sufficient to affect Tribal marina operators. Access or damage to culturally important plants and resources would also be affected under Alternative F. No impacts on Tribal values related to TMFs or mechanical removal of trout would occur because these actions are not allowed under this alternative. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) from those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A.

In summary, under Alternative F there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values in Upper and Lower Grand Canyon private whitewater boating and in use values economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.7 Alternative G

Under Alternative G, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,143.3 million (0.3% increase) in use value and $4,997.1 million (0.4% decrease) at Lake Powell, while commercial and private whitewater boating would produce $247.6 million (13.7% decrease) and $68.5 million (a 0.6% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative G on humpback chub populations and sandbars in the Grand Canyon are estimated to be $3.5 billion at the national level and $19 million at the local (eight-county) level.

Under Alternative G, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,550 jobs and $308.0 million in income annually over the 20-year LTEMP period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,706 jobs and $311.6 million in income would be produced annually across all reservoir and river recreational activities under Alternative G over the 20-year LTEMP period.

Under Alternative G, there would be an estimated average 24.5 HFEs over the LTEMP period and a maximum of 18 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Small reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative G compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the equal monthly volumes that would occur year-round, and consequently lower flows during the more popular summer months. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative G compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative G, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative G over the 20-year study period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings. Operation of new powerplants with Alternative G would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative G would have impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities, and would mean the loss of 25 total (direct and indirect) jobs and $1.2 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative G, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on

Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be higher (as much as \$1.34/MWh) from those on non-Tribal customers, and would be greater (as much as \$2.84/MWh) than those under Alternative A.

In summary, under Alternative G there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values for Lower Grand Canyon private whitewater boating and in use values and economic activity associated with Lake Mead recreation. There would also be increased economic activity from customer utility capacity expansion, compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.15 AIR QUALITY

This section describes potential impacts of the LTEMP alternatives on ambient air quality in the immediate vicinity of GCNP and over the 11-state study area within the Western Interconnection, where the air quality would potentially be affected by the proposed action. The regional air quality setting is described in Section 3.15.

Issue: How do alternatives affect emissions from other facilities and air quality in the Grand Canyon area and in the 11-state study area?

Impact Indicators:

- Visibility effects from sulfates and nitrates
- SO_2 and NO_x emissions

4.15.1 Analysis Methods

Glen Canyon Dam hydropower generation does not generate air emissions. However, dam operations can affect emissions within the SLCA/IP system, which is referred to here as “the system.” It also impacts emissions and ambient air quality over the 11-state Western Interconnection region, which includes Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, because hydropower generation offsets generation from other generating facilities (i.e., coal-fired, natural gas-fired,) in the Western Interconnection. Differences among alternatives in the amount of generation at peak demand hours could affect regional air emissions, if lost generation was offset by generation from coal, natural gas, or oil units.

Air quality issues within the study area are discussed in Section 3.15 and notably include visibility degradation in Federal Class I areas. Coal, natural gas, and oil units emit SO_2 and NO_x, which are precursors to sulfate and nitrate aerosols, respectively. These aerosols play an important role in visibility degradation by contributing to haze. Among anthropogenic sources, sulfate is a primary contributor to regional haze in the Grand Canyon, and nitrate is a minor contributor. Effects on visibility are analyzed through a comparison of regional SO_2 and NO_x emissions under the various alternatives.

To compute total air emissions under the alternatives, emissions were summed from all generating facilities in the SLCA/IP system. This analysis was based on the analysis performed for hydropower, which estimated electrical power contributions for the same facilities (results are discussed in Section 4.13). Emissions were computed according to the estimated electricity generation of each facility and for electricity traded on the spot market under each alternative by calendar year. The spot market represents the interface of the system with the greater Western Interconnection region and accounts for effects of Glen Canyon Dam operations outside of the system. For individual powerplants in the system, pollutant emission factors (in pounds per megawatt-hour [lb/MWh]) available in the *Emissions & Generation Resource Integrated Database* (eGRID) (EPA 2014a) were used to compute emissions. For unspecified powerplants (e.g., long term contract), composite emission factors were employed that are representative of power generation from all types of powerplants currently in operation over the Western Interconnection. Composite emission factors are estimated to be 0.74 and 1.07 lb/MWh for SO_2 and NO_x, respectively. For spot market purchases and sales, composite emission factors were used that are representative of power generation from gas powerplants currently in operation over the Western Interconnection, based on the assumption that spot market generation is primarily to serve peak loads. Composite emission factors are estimated to be 0.0083 and 0.266 lb/MWh for SO_2 and NO_x, respectively. For advanced natural-gas-fired simple cycle and combined cycle generating units to be built in the future, emission factors in EIA (2013) were used: 0.001 lb/MMBtu for SO_2 for both simple cycle (0.0098 lb/MWh) and combined cycle (0.0064 lb/MWh); 0.03 lb/MMBtu (0.29 lb/MWh) for simple cycle and 0.0075 lb/MMBtu (0.048 lb/MWh) for combined cycle for NO_x. Note the difference in the expression of emission factors employed from different sources. Emission factors for existing plants and the spot market are based on emissions per electricity output, while those for future plants are based on emissions per heat energy input (fuel burned). To make comparable estimates, the thermal efficiency of the plant must be taken into account for the latter case.

Potential impacts on regional ambient air quality associated with dam operations are compared in terms of air emissions among alternatives relative to air emissions for Alternative A (No Action Alternative).

4.15.2 Summary of Impacts

The geographic area of potential impacts consists of the GCNP vicinity and the 11-state Western Interconnection region. Table 4.15-1 presents potential impacts on ambient air quality that would likely result from each alternative. Due to very small differences in SO_2 and NO_x precursor emissions, negligible differences are expected among the alternatives with regard to visibility and haze in the region.

TABLE 4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air Quality

Air Quality	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions	Negligible increase (0.01%) in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease (–0.01%) in SO_2 emissions and no change in NO_x emissions compared to Alternative A	No change in SO_2 emissions and negligible increase in NO_x emissions compared to Alternative A	Negligible increase (<0.005%) in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease (–0.04%) in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease (–0.03%)in SO_2 and negligible increase in NO_x emissions compared to Alternative A
Visibility[a]	No change from current conditions	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A
Air Quality in 11-State Western Interconnection Region							
SO_2 emissions (tons/yr)[b]	42,465	42,471	42,463	42,465	42,466	42,448	42,453
	No change from current conditions	Negligible increase (0.01%)	Negligible reduction (–0.01%)	No change from current conditions	Negligible increase (<0.005%)	Negligible reduction (–0.04%)	Negligible reduction (–0.03%)
NO_x emissions (tons/yr)[b]	78,496	78,501	78,496	78,503	78,500	78,487	78,498
	No change from current conditions	Negligible increase (0.01%)	No change from current conditions	Negligible increase (0.01%)	Negligible increase (<0.005%)	Negligible reduction (–0.01%)	Negligible increase (<0.005%)

[a] Visibility effects are estimated from expected changes in the emissions of sulfate and nitrate precursors, SO_2 and NO_x.

[b] Total air emissions and percent change in emissions (compared to Alternative A) from combustion-related powerplants in the system averaged over the 20-year LTEMP period.

Source: EPA (2014b).

Differences in emissions, and thus in impacts on air quality, under the LTEMP alternatives depend on four factors that may act to increase or decrease total emissions under a given alternative. These factors include:

- Total electricity generation at Glen Canyon Dam;
- Generation profile as characterized by the hourly, daily, and monthly release pattern;
- Amount and timing of needed replacement capacity needed to offset reduced Glen Canyon Dam capacity; and

- Amount of exports and imports of electricity to and from the spot market.

As total generation decreases, overall emissions increase because compensating generation includes a component of combustion sources within the system. The differences among the alternatives in total generation are relatively small (<2%), and are related to differences in the amount of water that bypasses the turbines during HFEs.

The generation profile of alternatives reflects the degree to which generation can meet peak demand. During low load periods Glen Canyon Dam electricity production displaces generation from baseload units such as coal-fired units that tend to have high emission rates in pounds (lb) of emissions per MWh generated; on-peak Glen Canyon generation displaces peaking unit production, typically natural gas-fired combustion turbines, which have lower emission rates than coal plants. Alternatives that have greater Glen Canyon Dam peaking generation have reduced Glen Canyon Dam baseload generation and vice versa, given approximately equal total flow volumes among the alternatives. Thus, fluctuating flow alternatives with greater Glen Canyon Dam peaking power and lower baseload power tend to result in higher SO_2 and NO_x emissions system-wide due the greater use of coal-fired facilities within the system to compensate for reduced baseload generation at Glen Canyon Dam. Coal-fired facilities have approximately an order of magnitude higher SO_2 and significantly higher NO_x emissions than gas-fired facilities for a given amount of generation. Coal plants also produce more CO_2, a greenhouse gas, than do gas-fired plants. Effects of greenhouse gas emissions are discussed in Section 4.16.

The amount and timing of needed replacement capacity can also have an effect on total emissions. Steady flow alternatives, which do not include load following have reduced effective capacity, or maximum generating level, which must be compensated for by the construction and operation of new generation facilities in the system to meet current and future demands during peak load periods. New capacity is required sooner under steady flow alternatives (Section K.1.10.2 in Appendix K). New units would tend to be cleaner, more efficient, and less expensive to operate and therefore would tend to displace generation from higher emitting old units that serve the same type of duty (i.e., peaking unit) and would thus tend to reduce system emissions slightly relative to fluctuating flow alternatives. Construction of new capacity and retirement of existing plants are included in the hydropower analysis (Section 4.13) and in this air quality analysis.

The relative amounts of exports and imports to and from the spot market also can affect total emissions. Alternatives with greater net exports (sales) from the SLCA/IP system to the spot market tend to have greater total emissions since fossil-fired powerplants in the SLCA/IP system tend to have higher emission rates than Western Interconnection powerplants in states which purchase the electricity, mostly in California. When the system buys external energy to serve electricity demand, it needs to produce less power from its own internal resources thereby reducing pollutants emitted by the system. Conversely, when the system sells power to the Western Interconnection, it increases power production to support the spot energy transaction. Emissions associated with spot market sales are accounted for because unit-level generation for all facilities in the system (including the amount required for a sale) is multiplied by plant-level emission factors. On the other hand, this exported energy via a spot market transaction will reduce both generation and emissions in the overall 11-state Western Interconnection.

These factors have relatively small effects on emissions, and operate in sometimes opposing directions with regard to total system emissions of SO_2, NO_x and CO_2. Thus, although total emissions under the various alternatives are relatively similar, the relative differences result from a complex combination of these four factors that can only be understood through detailed modeling of emissions from individual generating facilities within the system under each of the alternatives. The following paragraphs present the results of such modeling.

Electricity generation averaged over the LTEMP period at Glen Canyon Dam for each alternative is shown in Figure 4.15-1. Little difference exists among alternatives, which range from 4,178 to 4,255 GWh per year. Other powerplants in the system can be fossil fuel–fired, renewable, hydro, or nuclear, and they depend on Glen Canyon Dam to provide uninterrupted power to their customers; power generation is thus similarly unchanged among alternatives. Under Alternative A, total SO_2 and NO_x emissions in the system averaged over the 20-year LTEMP period are estimated to be about 42,465 tons/yr and 78,496 tons/yr, which amount to about 10% and 3.0%, respectively, of total SO_2 and NO_x emissions over the Western Interconnection region (see Table 3.16-3). Thus, air emissions from power generators in the system are moderate contributors to total emissions in the Western Interconnection region. As shown in Table 4.15-1, air emissions under other LTEMP alternatives are similar to those under Alternative A. Differences from Alternative A range from –0.04 to 0.01% for SO_2 and from –0.01 to 0.01% for NO_x. Differences in average annual emissions range from –18 to 5 tons/yr for SO_2 and –10 to 6 tons/yr for NO_x, compared to those for Alternative A. Therefore, potential impacts of dam operations under various alternatives on regional air quality would be very small.

Table 4.15-2 presents a breakdown of emission sources by generation technology type for the generation facilities within the system and includes emissions for energy traded on the spot market using a composite emission factor for facilities in the Western Interconnection region. The table also shows power generation from Glen Canyon Dam under the various alternatives relative to Alternative A, which produces the most energy. Alternatives F and G produce relatively less hydropower energy than Alternative A (98.3% and 98.2%, respectively) because they have more HFEs in which a portion of released water bypasses the powerplant turbines.

SO_2 and NO_x emissions within the system are dominated by steam turbine technologies, mainly coal-fired powerplants (Table 4.15-2). Considering generation by facilities within the system (approximately 35 primary facilities), the differences among alternatives in estimated emissions are miniscule, ranging over only 0.05% for SO_2 and 0.02% for NO_x (system subtotal). Estimated differences among alternatives reflect slight differences in the contributions from various powerplant technologies; these are attributed to small differences in baseload and peaking energy provided by Glen Canyon Dam. Gas turbine peaking plant technologies produce lower SO_2 and lower NO_x emissions than baseload coal-fired plants. Thus, offsetting gas turbine peaking power with hydropower from Glen Canyon Dam has a lower effect on total system emissions than does offsetting coal-fired baseload with baseload energy from Glen Canyon Dam.

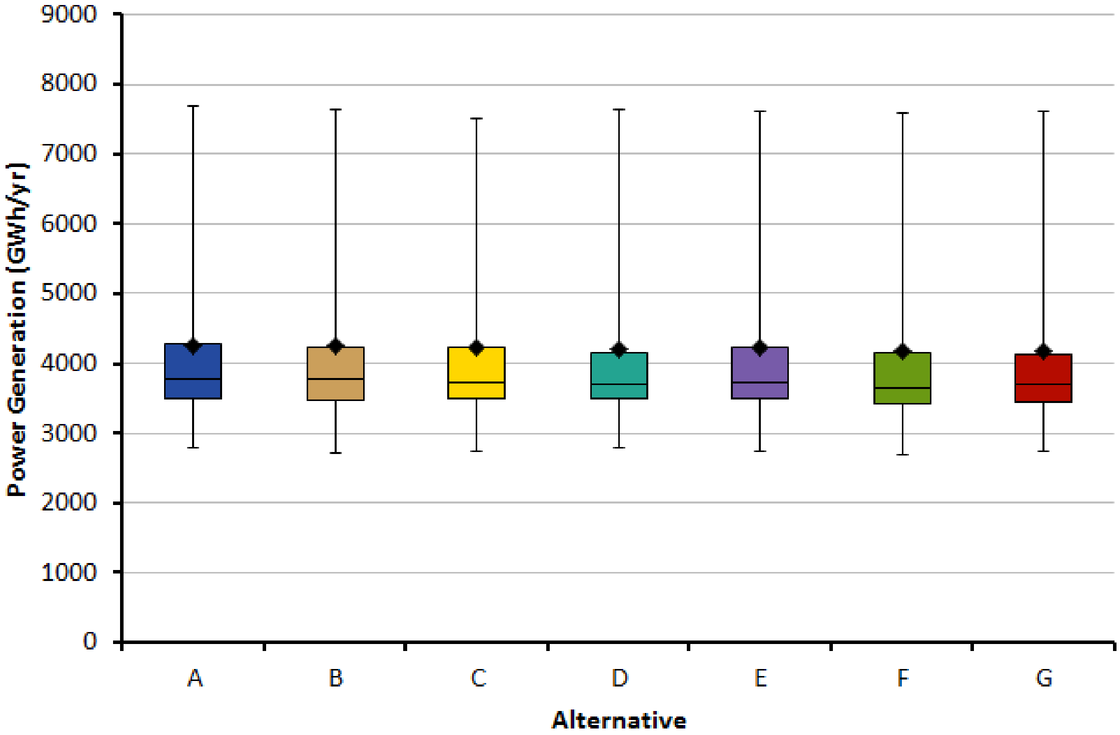

FIGURE 4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

This effect may be seen by comparing emissions subtotals by technology type under fluctuating flow and steady flow alternatives. For both SO_2 and NO_x, steam turbine (coal plant) emissions are slightly lower under Alternatives F and G, reflecting possible reductions in baseload emissions from coal plants offset by increased baseload energy from Glen Canyon Dam, even though these two alternatives generate <2% less Glen Canyon Dam energy than the fluctuating flow alternatives. Likewise, SO_2 emissions for gas technologies are slightly higher for Alternatives F and G, reflecting increased peaking generation from gas plants compensating for lack of peaking ability under these two alternatives.

The effects of the spot market on total system emissions are shown in Table 4.15-2. The spot market contribution to emissions is small (about <0.2% of total emissions from the system); however, for NO_x the spot market contributes about 60% more than the in-system component to differences among alternatives (21 tons/yr and 13 tons/yr, respectively). The spot market has no effect on differences in SO_2 emissions, since spot market emissions are very small and similar (4 tons/yr) (Table 4.15-1). The spot market component is shown as a negative value in the table, reflecting a net export of power from the system. When power is exported (i.e., sold) to a utility outside of the system, it is assumed that the purchaser will generate less energy from its own power resources, resulting in lower total emissions in the Western Interconnection region. Therefore, we apply an emissions credit for energy that is bought by utilities outside of the system. Because we do not model external utilities in detail, we cannot pinpoint the exact source

TABLE 4.15-2 Distributions of SO_2 and NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative

	Alternative						
Generation Type	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Total Glen Canyon Dam Power Generation Relative to Alternative A (MW-hr/day) (% of Alternative A)	11,650 (100%)	11,616 (99.7%)	11,566 (99.3%)	11,525 (98.9%)	11,571 (99.3%)	11,449 (98.3%)	11,438 (98.2%)
SO_2 Emissions (tons per year)							
System Power Generation							
Combined Cycle	44	44	44	44	44	44	44
Composite[a]	606	607	606	607	607	608	606
Gas Turbine	13	13	13	13	13	15	14
Internal Combustion	1	1	1	1	1	1	1
Steam Turbine	41,805	41,810	41,802	41,804	41,805	41,785	41,792
System Subtotal	**42,469**	**42,474**	**42,467**	**42,469**	**42,470**	**42,452**	**42,457**
Spot Market[b]							
Sales (emissions subtracted)	–16	–15	–16	–16	–16	–16	–16
Purchases (emissions added)	12	12	12	12	12	12	12
Spot Market Subtotal	**–4**	**–4**	**–4**	**–4**	**–4**	**–4**	**–4**
Total (System + Spot Market)	**42,465**	**42,471**	**42,463**	**42,465**	**42,466**	**42,448**	**42,453**
NO_x Emissions (tons per year)							
System Power Generation							
Combined Cycle	655	654	656	657	656	658	658
Composite[a]	869	870	869	870	870	871	869
Gas Turbine	271	265	282	278	277	307	300
Internal Combustion	24	24	24	24	24	24	24
Steam Turbine	76,800	76,806	76,796	76,799	76,801	76,766	76,781
System Subtotal	**78,620**	**78,620**	**78,626**	**78,629**	**78,628**	**78,626**	**78,632**
Spot Market Sales[b]							
Sales (emissions subtracted)	–499	–492	–509	–503	–506	–520	–514
Purchases (emissions added)	375	374	378	377	378	381	380
Spot Market Subtotal	**–124**	**–118**	**–130**	**–126**	**–128**	**–139**	**–134**
Total (System + Spot Market)	**78,496**	**78,501**	**78,496**	**78,503**	**78,500**	**78,487**	**78,498**

[a] Unspecified generation type.

[b] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

of this emission reduction. Therefore, we use composite emission factors representative of power generation in the 11-state Western Interconnection region. Note, however, that since we model all generating resources within the system we are accounting for the increased generation and hence emissions associated with the exported energy.

Net NO_X emissions related to spot market sales and purchases are lowest (greatest negative value) for the steady flow Alternatives F and G, and highest for the fluctuating flow Alternatives B and A. Net SO_2 spot market emissions are essentially the same across alternatives. This result can be explained by considering in-system generation selling to the spot market. Under steady flow Alternatives F and G, the Glen Canyon Dam powerplant does not provide peaking power, while under fluctuating flow Alternatives A-E it does. Since spot market sales typically serve peak demand, NO_X emissions from sales to the spot marker are therefore higher for Alternatives F and G, since other, typically gas-fired, facilities in the system provide peak generation. Such facilities generate NO_X emissions, but very little SO_2, so there is no effect on the latter emission.

Given the very small differences in the estimated emissions after considering all of the factors discussed above and in light of the uncertainty of emissions modeling, it may be concluded that emissions would be similar under all of the alternatives.

4.15.3 Alternative-Specific Impacts

Although differences are expected in potential ambient air quality and associated impacts among the various alternatives, potential air quality impacts are anticipated to be negligible. The modeled differences among alternatives are presented below. Detailed information on alternatives and hydropower assumptions and modeling can be found in Sections 2.3 and 4.13, respectively.

4.15.3.1 Alternative A (No Action Alternative)

Under Alternative A (No Action Alternative), annual power generation at Glen Canyon Dam would range from 2,781 to 7,677 GWh, with an average of 4,225 GWh, over the 20-year LTEMP period. Coal-fired steam plants account for the vast majority of these emissions; that is about 98% of both SO_2 and NO_X emissions. In addition, total LTEMP-related annual air emissions from power generation, system emissions plus changes in the Western Interconnection would range from 41,392 to 42,991 tons/yr with an average of 42,465 tons/yr for SO_2, and from 77,121 to 80,005 tons/yr with an average of 78,496 tons/yr for NO_X. These annual-average emissions for SO_2 would be about 10% and for NO_X would be about 3.0% of the total air emissions over the Western Interconnection region (see Table 3.16-3).

4.15.3.2 Alternative B

Under Alternative B, total LTEMP-related annual-average air emissions are 42,471 tons/yr for SO_2 and 78,501 tons/yr for NO_X; these values are about 0.01% higher than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.7% of that under Alternative A. Total annual emissions from power generation in the region are slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative B and Alternative A.

4.15.3.3 Alternative C

Under Alternative C, total LTEMP-related annual-average air emissions are 42,463 tons/yr for SO_2 and 78,496 tons/yr for NO_X; these values are about 0.01% lower than and the same as those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower than or the same as those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative C and Alternative A.

4.15.3.4 Alternative D (Preferred Alternative)[37]

Under Alternative D, total LTEMP-related annual-average air emissions are 42,465 tons/yr for SO_2 and 78,503 tons/yr for NO_X; these values are the same as and about 0.01% higher than those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.9% of that under Alternative A. Total annual emissions from power generation in the region are the same as or slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative D and Alternative A.

4.15.3.5 Alternative E

Under Alternative E, total LTEMP-related annual-average air emissions are 42,466 tons/yr for SO_2 and 78,500 tons/yr for NO_X; these values are about <0.005% higher than those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative E and Alternative A.

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[37] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on air quality.

4.15.3.6 Alternative F

Under Alternative F, total LTEMP-related annual-average air emissions are 42,448 tons/yr for SO_2 and 78,487 tons/yr for NO_x; these values are about 0.04 and 0.01%, respectively, lower than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative F and Alternative A.

4.15.3.7 Alternative G

Under Alternative G, total LTEMP-related annual-average air emissions are 42,453 tons/yr for SO_2 and 78,498 tons/yr for NO_x; these values are about 0.03 and <0.005%, respectively, lower and higher than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.2% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower or higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative G and Alternative A.

4.16 CLIMATE CHANGE

There is the potential for the LTEMP to affect climate change indirectly through changes in dam operations, and for dam operations under the LTEMP to be affected by climate change. Although each of the LTEMP alternatives would generate approximately the same amount of electrical power,[38] there are relatively large differences in the monthly and within-day pattern of releases that affect hydropower capacity. These differences in available capacity affect how other power facilities in the region respond to changes in demand, and in this way can affect the total system emission of carbon dioxide (CO_2) and other greenhouse gases (GHGs) (Section 4.15 describes the effect of Glen Canyon Dam operations on the power system and the emissions of criteria pollutants). In addition to these potential effects on climate change, operations over the 20-year LTEMP period could be

Issue: How could the LTEMP affect or be affected by climate change?

Impact Indicators:

- Changes in CO_2 and other GHG emissions under different LTEMP alternatives
- Climate-driven changes in hydrology and sediment inputs over the 20-year LTEMP period

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[38] The relatively small expected differences among alternatives in the amount of total annual generation relate to the alternative-specific frequency of HFEs. Approximately 14,000 cfs of a 45,000-cfs HFE would be released through the bypass tubes, which do not generate power. Alternatives differ substantially in the frequency of HFEs (Section 4.2).

affected by climate-driven changes in hydrology (inflow patterns and evaporation rates) and sediment inputs. Reductions in inflow due to changes in precipitation and increases in evaporation rates resulting from increases in temperature could result in decreases in the elevation of Lake Powell, with subsequent reductions in power generation resulting from decreased head, and potentially an increase in the frequency of dropping below the power pool.

4.16.1 Analysis Methods

The analysis of GHG emissions and climate change was conducted based on the latest CEQ Guidance (CEQ 2016). The guidance recommends that NEPA analyses take into account available data and use GHG quantification tools for determining projected GHG emissions, which can be used as a proxy for assessing potential climate change effects of a proposed action and alternatives. In addition, when addressing climate change, agencies should consider: (1) the potential effects of a proposed action on climate change as indicated by changes in GHG emissions; and (2) the effects of climate change on a proposed action and its environmental impacts. These two components of the climate change analysis are provided in Sections 4.16.1.1 and 4.16.1.2, respectively.

4.16.1.1 Effects of LTEMP Alternatives on Climate Change

The buildup of heat-trapping GHGs can over time warm Earth's climate and result in adverse effects on ecosystems and human health and welfare. Thus, cumulative GHG emissions can be used as a surrogate to assess climate-change impacts. Such effects would be global and are not particularly sensitive to GHG source locations because GHGs are mostly long-lived and spread across the entire globe.

Glen Canyon Dam operation does not generate GHG emissions, but dam operations can indirectly affect climate change, regionally and globally, through varying contributions to the total mix of power generation in the region, which also includes coal-fired, natural gas–fired, hydroelectric, nuclear, and renewable generation sources. For the purposes of this analysis, the principal GHG of concern is CO_2, which accounts for more than 99% of GHG emissions related to power generation. However, facility- or technology-specific GHG emission factors also consider other GHGs, such as methane (CH_4) and nitrous oxide (N_2O), albeit to a small degree.

To compute total GHG emissions under the alternatives, emissions were summed from all generating facilities primarily affected by Glen Canyon Dam operations, referred to as "the system," as was done for SO_2 and NO_x for the air quality analysis (Section 4.15). This analysis was based on the analysis performed for hydropower, which estimated electrical power contributions for the same facilities, the results of which are discussed in Section 4.13. GHG emissions were computed according to the estimated annual electricity generation of each facility and for electricity traded on the spot market under each alternative. For individual powerplants, GHG emission factors (in lb/MWh) available in eGRID (EPA 2014a) were used to compute

GHG emissions. For unspecified powerplants (e.g., long-term contract), composite emission factors representative of power generation from all types of powerplants that are currently in operation over the 11-state Western Interconnection region (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) were employed. A composite emission factor for GHGs is estimated to be 963 lb/MWh (0.437 MT/MWh) for CO_2 equivalent (CO_2e).[39] For spot market purchases and sales, a composite GHG emission factor for gas powerplants operating in the Western Interconnection was used, and was estimated to be 888 lb/MWh (0.403 MT/MWh) CO_2e. For advanced natural gas–fired generating units projected to be built in the future, an emission factor from the EIA (2013) of 117 lb/MMBtu (0.053 MT/MMBtu) for CO_2 was used for both simple-cycle (1,141 lb/MWh [0.518 MT/MWh]) and combined cycle (752 lb/MWh [0.341 MT/MWh]) units.

Potential impacts on climate change associated with dam operations are evaluated for the LTEMP alternatives though a comparison of GHG emissions to those for Alternative A (no action alternative).

4.16.1.2 Effects of Climate Change on Hydrology and Downstream Resources

The effects of climate change on hydrology were treated as an uncertainty in the analyses of hydrology and downstream resource impacts, rather than by means of a full-fledged climate analysis and adaptation approach. The LTEMP EIS has the more limited scope of evaluating future dam operations, management actions, and experimental options to provide a framework for adaptively managing Glen Canyon Dam over the next 20 years to protect and minimize adverse impacts on downstream natural and cultural resources in GCNRA and GCNP. Accordingly, DOI used a sensitivity analysis approach to see how robust the alternatives would be with regard to their impact on resources under climate change.

The Basin Study (Reclamation 2012e) suggested there could be significant increases in temperature and decreases in water supply to the Colorado River system below Glen Canyon Dam over the next 50 years, driven by global climate change. The magnitude of these changes is uncertain. In addition, there could be changes to sediment input (especially from the Paria and Little Colorado Rivers), driven by complex local and regional climate changes, but the direction and magnitude of these changes are uncertain. Water supply, sediment supply, and temperature are important factors that affect all of the resources under consideration in the LTEMP EIS.

The approach used in this EIS treats climate change as an external uncertainty and analyzes the robustness of the alternatives to uncertainties in the water and sediment inputs. This approach required: (1) use of 21 hydrologic and 3 sediment scenarios based on historic conditions; (2) estimation of the likelihood of the scenarios under climate change; and (3) analysis of the impacts of alternatives under all hydrologic and sediment scenarios. The approach analyzed how robust the alternatives would be to climate change-driven hydrologic and

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[39] CO_2e is a measure used to compare the emissions from various GHGs on the basis of their global warming potential, defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period (usually 100 years).

sediment inputs. For the climate-change analysis, the 21 hydrologic traces used in the LTEMP analysis were weighted according to their frequency of occurrence (based on mean annual inflow to Lake Powell) in the Basin Study's 112 simulations. Figure 4.16-1 shows the weights assigned to each hydrologic trace. As shown in Figure 4.16-2, the 21 hydrologic traces were not representative of the full range of expected inflow variation under a climate-change scenario and did not include the driest traces expected under climate change. About 30% of the forecast distribution was not captured by the historic traces.

Modeling results for downstream resource effects were generated for the 21 historic hydrology traces and 3 historic sediment traces. For the analyses presented in Sections 4.2 through 4.10, the hydrology traces were weighted equally to represent their equal probability of occurrence in the absence of climate change. The climate-change weights shown in Figure 4.16-1 were applied to the modeled results for each trace to represent their probability of occurrence under climate change.

4.16.2 Summary of Impacts

4.16.2.1 Effects of LTEMP Alternatives on Climate Change

Table 4.16-1 presents total estimated GHG emissions within the system for each alternative. These emissions are an indication of the potential relative impact of the alternatives on climate change.

For estimating GHG emissions attributable to Glen Canyon Dam operations, projected power generation at the dam was averaged over the 20-year LTEMP period (Figure 4.15-1). Little difference exists among the alternatives, which range from 4,178 to 4,255 GWh per year, amounting to 1.8%. Power generation from other powerplants in the system and in the Western Interconnection region also would be similar among alternatives. For Alternative A (no action alternative), total GHG emissions in the system averaged over the 20-year LTEMP period are estimated to be about 55,177,668 MT/yr, which amounts to about 4.5% and 0.81% of total GHG emissions over the Western Interconnection region and the United States, respectively (Table 3.15-3, Section 3.15.3). Thus, GHG emissions from power generation are relatively small contributors to total GHG emissions, both in the region (11 Western Interconnection states) and in the United States.

Changes in total GHG emissions (i.e., emissions from system generation, and spot market sales and purchases) under other LTEMP alternatives relative to Alternative A would range from an increase of 5,900 MT/yr (Alternative B) to 44,522 MT/yr (Alternative F). On a percentage basis, differences from Alternative A would range from 0.011% (Alternative B) to 0.081% (Alternative F). The system includes 35 power generation facilities analyzed individually. The spot market reflects the effects of Glen Canyon Dam operations on the larger Western Interconnection region and represents an offset of about 1% of system emissions (Table 4.16-1).

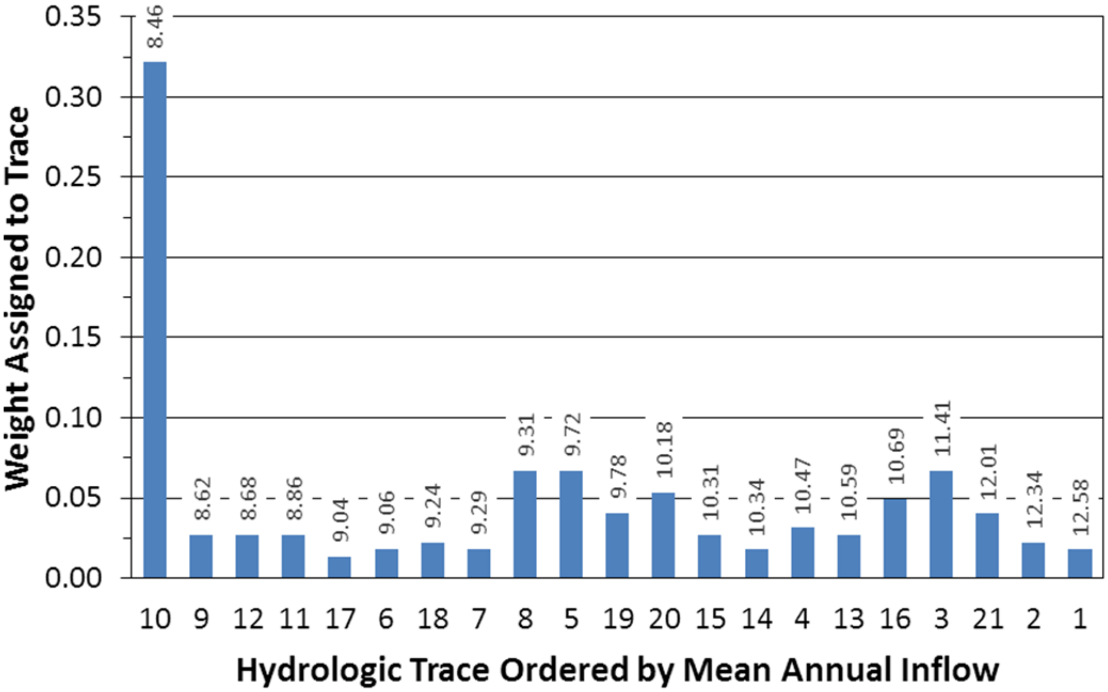

FIGURE 4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions under Climate Change (Numbers at top of bars are mean annual inflow of each trace in million acre-feet.)

In light of the 1.8% range in Glen Canyon Dam hydropower generation under the alternatives, and assuming that reduction in hydropower generation at Glen Canyon Dam is made up by fossil fuel generation facilities in the system, the smaller range in GHG emissions of only 0.081% suggests that reduced hydropower energy from, for example, Alternatives F and G does not result in a corresponding increase in GHG emissions from compensating generation at other thermal powerplants in the system. This result may be explained by examining the effects of powerplant mix and capacity expansion on emissions under the various alternatives. With respect to powerplant mix, the Glen Canyon Dam powerplant under the steady-flow Alternatives F and G does not serve peak loads, but does so under the fluctuating-flow Alternatives A through E, offsetting GHG emissions from other peaking facilities in the system, mainly gas turbines. Conversely, steady-flow alternatives can provide a higher level of baseload power, which can offset emissions from other baseload facilities in the system, mainly coal-fired facilities with relatively high GHG emissions compared to gas turbines. More detailed discussion of these factors is presented in Section 4.15.2.

Reviewing projected GHG emissions at specific powerplants within the system, the steady-flow Alternatives F and G, although they result in the highest overall GHG emissions, are expected to result in lower GHG emissions from baseload coal-fired plants (categorized as steam turbine technologies) and higher GHG emissions from gas turbine plants as compared to the fluctuating-flow Alternatives A through E. This comparison supports the conclusion that

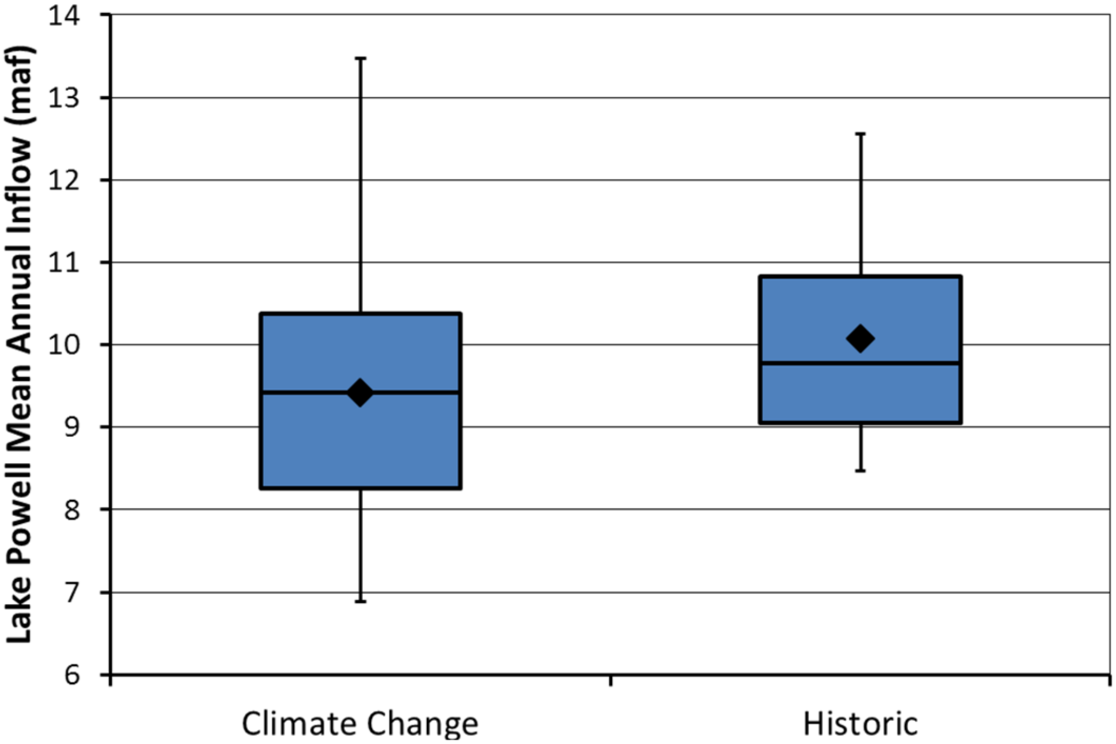

FIGURE 4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 112 Climate-Change Inflow Traces and 21 Historic Inflow Traces (Means were calculated as the average for all years within each of the traces. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Alternatives F and G tend to offset a relatively greater amount of baseload power at combustion facilities in the system than do Alternatives A through E, while the latter alternatives offset relatively more emissions from gas turbines that provide peaking power.

GHG emissions under the alternatives can also be compared to both total 11-state GHG emissions at 1,226.3 million MT CO_2e in 2010 (see Table 3.15-3) and total U.S. GHG emissions at 6,810.3 million MT CO_2e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions from Alternative A range from 0.0005% (Alternative B) to 0.0036% (Alternative F) relative to total 11-state GHG emissions, and from 0.00009% (Alternative B) to 0.00065% (Alternative F) relative to total U.S. GHG emissions.

CO_2, CH_4, and N_2O are emitted from the reservoirs associated with the Glen Canyon Dam, Lake Powell, and Lake Mead. For example, CH_4 from large dams accounted for about 4% of human-caused climate change (Lima et al. 2008). GHG emissions from biomass decay, including CH_4, in such reservoirs, have been a subject of recent debate (Pacca and Horvath 2002). Through consumption of atmospheric CO_2 by photosynthesis in plankton and aquatic plants in reservoirs, net CO_2 emissions from dam operations may be small, and uptake by reservoirs can occasionally exceed emissions. Emissions of CH_4 are possible from turbines and

TABLE 4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions

	GHG Emissions by Alternative (MT/yr)[a,b]						
GHG Emissions Source	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Overall summary of impacts	No change from current conditions.	Compared to Alternative A, 0.011% increase in GHG emissions.	Compared to Alternative A, 0.033% increase in GHG emissions.	Compared to Alternative A, 0.042% increase in GHG emissions.	Compared to Alternative A, 0.030% increase in GHG emissions.	Compared to Alternative A, 0.081% increase in GHG emissions.	Compared to Alternative A, 0.074% increase in GHG emissions.
System power generation							
Combined cycle	5,871,619	5,867,894	5,875,470	5,878,837	5,876,226	5,880,006	5,885,763
Composite[c]	711,604	712,068	711,574	712,296	712,186	713,199	711,081
Gas Turbine	622,805	611,925	661,049	646,520	647,637	730,920	695,498
Internal combustion	1,726	1,721	1,680	1,728	1,711	1,688	1,706
Steam turbine	48,344,640	48,348,638	48,341,590	48,343,248	48,344,880	48,319,488	48,332,026
System subtotal	55,552,395	55,542,246	55,591,363	55,582,629	55,582,640	55,645,301	55,626,074
Spot market[d]							
Sales (emissions subtracted)	–1,512,509	–1,493,787	–1,543,444	–1,525,109	–1,536,444	–1,577,799	–1,560,383
Purchases (emissions added)	1,137,782	1,135,108	1,147,910	1,143,056	1,147,975	1,154,687	1,152,937
Spot market subtotal	**–374,727**	**–358,679**	**–395,534**	**–382,053**	**–388,469**	**–423,112**	**–407,447**
Total emissions (system + spot market)	**55,177,668**	**55,183,567**	**55,195,829**	**55,200,576**	**55,194,171**	**55,222,189**	**55,218,627**
Change in Total Emissions from Alternative A (MT/yr)[e]	0	5,900	18,161	22,908	16,503	44,522	40,960
	No change from current conditions	0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase
Change as % of total 11-state GHG emissionsf	No change from current conditions	0.0005% increase	0.0015% increase	0.0019% increase	0.0013% increase	0.0036% increase	0.0033% increase

TABLE 4.16-1 (Cont.)

	GHG Emissions by Alternative (MT/yr)[a,b]						
GHG Emissions Source	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Change as % of total U.S. GHG emissions[g]	No change from current conditions	0.00009% increase	0.00027% increase	0.00034% increase	0.00024% increase	0.00065% increase	0.00060% increase

[a] GHG emissions are expressed in CO_2e.

[b] GHG emissions (metric tons) from combustion-related powerplants in the system or in the region averaged over the 20-year LTEMP period. To convert from metric ton to ton, multiply by 1.1023.

[c] Unspecified generation type.

[d] “Sales” refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. “Purchases” refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

[e] Using an online tool from the EPA (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator), one can express a given amount of GHG emissions in metric tons in everyday terms. For example, 1 million MT/yr is estimated to be equivalent to the amount of CO_2 that is emitted as a result of the electricity use of 148,000 households. However, because the EPA cautions that these estimates are approximate and should not be used for emission inventory or formal carbon footprinting exercises.

[f] Total 11-state GHG emissions at 1,226.4 million MT/yr CO_2e in 2010 (see Table 3.15-3).

[g] Total U.S. GHG emissions at 6,810.3 million MT/yr CO_2e in 2010 (EPA 2013d).

spillways and downstream of dams. Reservoirs such as Lake Powell and Lake Mead would be expected to produce some amount of GHG emissions consistent with levels reported for reservoirs in the semiarid western United States (Tremblay et al. 2004), but the GHG emissions from these reservoirs are not anticipated to be different among the alternatives.

As discussed in this section, increases in GHG emissions among alternatives compared to Alternative A would be small, ranging from 5,900 MT/yr for Alternative B to 44,522 MT/yr for Alternative F, which corresponds to a 0.011% to 0.081% relative change from Alternative A. However, the totality of climate change impacts is not attributable to any single action. Albeit a small contribution, this project-related emission in combination with a variety of GHG emission sources around the world could exacerbate climate-related impacts, some of which are presented in Section 3.16. In contrast, climate change would be anticipated to have an impact on the proposed action and any alternative actions, such as hydrology and downstream resources, which are discussed in Section 4.16.2.2.

4.16.2.2 Effects of Climate Change on Hydrology and Downstream Resources

As discussed in Section 4.16.1.2, the climate-change analysis approach used the historic hydrology as its basis, but gave greater weight to drier years to represent their expected increased frequency of occurrence under a climate-change scenario. As shown in Figure 4.16-2, this approach underestimated the occurrence of the driest years, but it allows a determination of the robustness of the alternatives to climate-change uncertainty.

Figure 4.16-3 presents the differences between historic and climate-change-weighted values of mean daily flow and mean daily change in flow for the LTEMP alternatives as a percentage of the historic values for the 25th percentile and mean of the two variables. Negative values indicate a decrease in the value under the climate-change scenario, while positive values indicate an increase under the climate-change scenario. Of the values examined (minimum, maximum, 25th percentile, 50th percentile, 75th percentile, and mean), the 25th percentile (representing flow under drier conditions) was the most affected. There was no difference between historic and climate-change-weighted minimum and maximum values, but this is an artifact of the weighting approach used. Because mean monthly volume equals the mean daily flow times the number of days in each month, the percentage differences in that variable are identical to those shown for mean daily flow in Figure 4.16-3. The following conclusions can be drawn from the patterns observed in Figure 4.16-3:

- The 25th percentile values of mean daily flow (and mean monthly volume values) would be very similar from October through March under climate-change and historic scenarios for all alternatives. The differences for all alternatives between historic and climate-change scenarios would increase month-by-month through August. The trend is toward lower mean daily flows under climate change, which reaches a maximum difference of about 10% to 18% (decrease from historic values) in August. In general, the differences among alternatives with respect to the effects of climate change on mean daily flow would be similar.

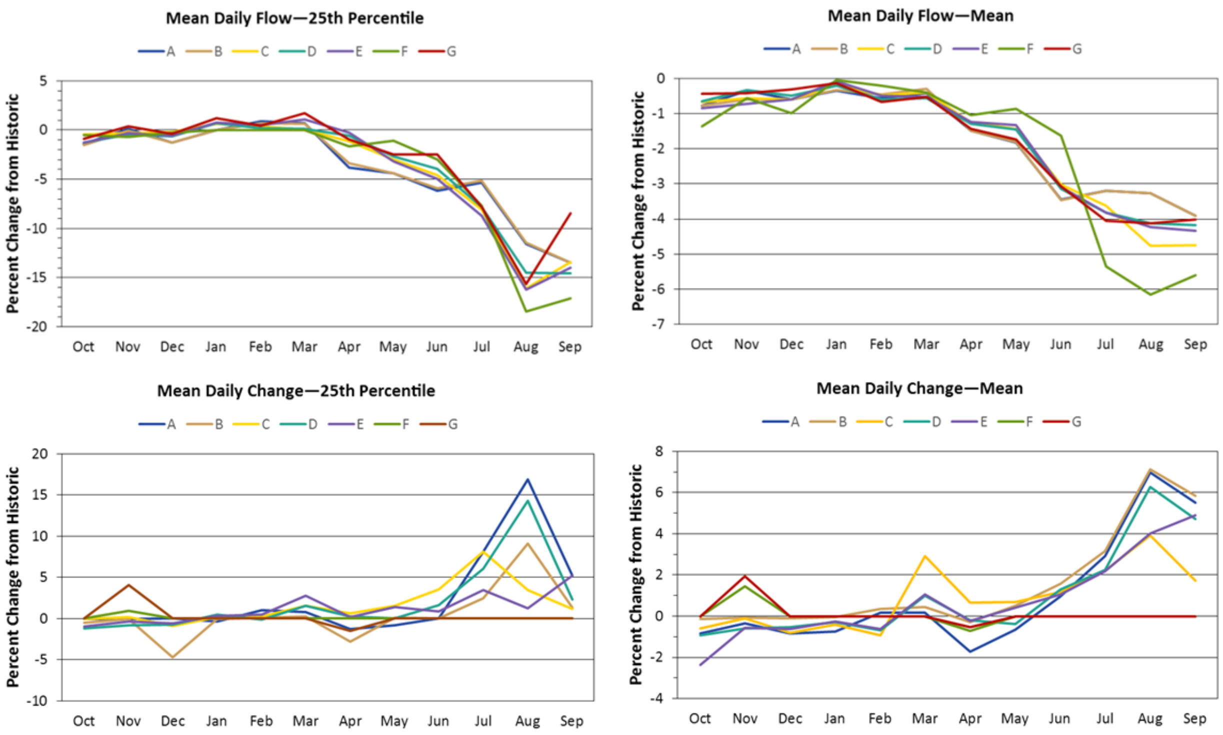

FIGURE 4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean Daily Flow and Mean Daily Change in Flow by Month for LTEMP Alternatives

- Mean values of mean daily flow (and values of mean monthly volume) would follow a pattern similar to that of the 25th percentile values of mean daily flow, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternative F in July and August, when flow would be even lower with climate change than under other alternatives.

The 25th percentile values of mean daily change under the climate-change scenario would be very similar to historic values from October through June for all alternatives, but would be higher than historic for July, August, and September for all alternatives except for the steady-flow Alternatives F and G. Under the drier conditions of climate change and lower mean daily flows, there is more flexibility to provide a wider range of flows within a day and still meet other operational constraints. It should be noted that the differences in mean daily change would be less than 1,000 cfs.

- Mean values of mean daily change would follow a pattern similar to that of the 25th percentile values of mean daily change, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternatives A, B, and D in August, when daily change would be even higher with climate change than under other alternatives.

The monthly increase in climate-change effects in mean daily flow and mean monthly volume results from operation of the dam based on the inflow forecast for the water year. Typically, operations in October, November, and December use volumes for an 8.23-maf year, with adjustments made in later months as forecasts indicate a drier or wetter year (Figure 4.2-1). Early forecasts (e.g., January) are subject to considerable uncertainty, and it is usually not until the April forecast that a reasonable identification of the annual volume can be made. Using this operational strategy under climate change would result in less water needing to be released after April, and therefore an increasing deviation from the historic pattern.

These differences in hydrology would influence the relative effect of LTEMP alternatives on resources, but, in general, the analysis conducted for this EIS indicates the differences would be relatively small (<5%) and not differ greatly among alternatives. Table 4.16-2 provides an overview of the expected effects on downstream resources. Under climate change, the impacts of most or all LTEMP alternatives would be less on sediment resources, humpback chub, trout, riparian vegetation, Grand Canyon cultural resources, Tribal values, and most recreation metrics, but there would be a reduction in the value of hydropower generation and capacity and an increase in impacts on Glen Canyon cultural resources.

4.16.3 Alternative-Specific Impacts

There are expected to be some differences in the emissions of GHGs among the LTEMP alternatives, as presented in this section. Detailed information on alternatives and hydropower assumptions and modeling can be found in Sections 2.3 and 4.13, respectively. The effects of climate change on hydrology and downstream resources are also presented.

4.16.3.1 Alternative A (No Action Alternative)

Under Alternative A (no action alternative), annual power generation would range from 2,781 to 7,677 GWh, with an average of 4,255 GWh over the 20-year (2014–2033) period. Total annual GHG emissions in the system related to power generation at the Glen Canyon Dam would range from 52,014,751 to 59,909,459 MT (from 57,336,449 to 66,038,875 tons), with an average of 55,177,668 MT (60,822,967 tons). These annual average GHG emissions would be about 4.5% and 0.81%, respectively, of the total GHG emissions over the Western Interconnection region and in the United States (see Table 3.15-3 and Section 3.15.3).

Based on the modeling performed and climate change weights applied to account for the greater likelihood of drier conditions under climate change, the following conclusions can be made. Temperature suitability for native and nonnative fish would be improved and impacts on humpback chub lessened. The overall number of trout is expected to decline, but the number of large trout would be higher than under historic hydrology. The impacts on native vegetation would be less. There would be a greater potential for impacts on cultural resources in both Glen Canyon and Grand Canyon, but an improvement in Tribal values for all metrics evaluated. Most

TABLE 4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under Climate Change Compared to Those under Historic Conditions

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions[a]
Hydrology	
Mean monthly volume and mean daily flow	Decrease in spring and summer, especially for Alternative F, with August being the month with the greatest departure from historic (11–19% reduction in 25th percentile values)
Mean daily change	Increase in July and August, especially for Alternatives A, B, and D (1–17% increase in fluctuating flow alternatives)
Sediment	
Sand load index (bar-building potential; higher is better)	Increase (2–4%) under Alternatives C–G; decrease (–2 to –3%) for Alternatives A and B
Sand mass balance index (higher is better)	Increase (4–9%) under all alternatives
Aquatic ecology	
Temperature suitability index—humpback chub (higher is better)	Increase under all alternatives (but especially Alternative F) in upstream reaches (RM 30–119); decrease at RM 157 under Alternatives A, B, and D, and all alternatives (except for Alternative F) at RM 213
Temperature suitability index—other native fish (higher is better)	Similar pattern as temperature suitability for humpback chub, but decrease at RM 157 only under Alternatives A and B; all alternatives would have decrease at RM 213
Temperature suitability index—coldwater nonnative fish (higher is better)	Increase under all alternatives at RM 0; decrease in all other downstream reaches
Temperature suitability index—warmwater nonnative fish (higher is better)	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Temperature suitability index—aquatic parasites (higher is better)	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Minimum number of adult humpback chub (higher is better)	Increase (0.2–2%) under all alternatives
Trout catch rate (age 2+, no./hr; higher is better)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout outmigrants (lower is better)	Increase (0.2–4%) under Alternatives C, D, E, and G; decrease (–1 to –4%) under Alternatives A, B, and F
Trout abundance (age 1+; higher or lower is better dependent on receptor)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout >16 in. total length (higher is better)	Increase (0.4–2%) under Alternatives A, B, C, and F; decrease (–0.1 to –1%) under Alternatives D, E, and G

TABLE 4.16-2 (Cont.)

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions[a]
Riparian vegetation	
Native species diversity and cover (index, higher is better)	Increase (1%) under Alternatives A, B, D, and E; decrease (–0.2 to –1%) under Alternatives C, F, and G
Cultural resources	
Effect of flows on Glen Canyon resources (index, higher is better)	Decrease under all alternatives (–10 to –17%)
Wind transport of sand to protect resources (index, higher is better)	Increase (3–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–1 to –2%)
Tribal values	
Riparian vegetation diversity	Increase (0.2–2%) under all alternatives, but Alternative F (–0.2%)
Marsh index (higher is better)	Increase (1–34%) under all alternatives
Mechanical removal of trout (lower is better)	Increase (2%) under Alternative G; decrease (–6 to –16%) under Alternatives A, B, and D; no removal under Alternatives C, E, and F
TMFs (lower is better)	Decrease (–7 to –17%) under Alternatives B, C, D, E, and G; no TMFs under Alternatives A and F
Recreation	
Camping area index (higher is better)	Increase (4–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–0.02 to –2%)
Fluctuation index (higher is better)	Decrease (–0.1 to –4%) under Alternatives A–E; no change in steady flow Alternatives F and G
Glen Canyon rafting use (number of passenger days lost due to HFEs)	Increase (0.1%) under Alternative F; decrease (–0.2 to –8%) under Alternatives A–E and G
Glen Canyon inundation index (higher is better)	Increase (0.5–0.8%) under all alternatives
Hydropower	
Annual net present value of generation	Decrease (–3%) under all alternatives
Net present value of capacity	Decrease (–2 to –4%) under all alternatives

[a] These results were obtained by applying the climate weights for each trace shown in Figure 4.16-1 to the modeling results presented in the various resource sections of Chapter 4 (Sections 4.2–4.13).

recreation metrics would reflect greater impacts under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.2 Alternative B

Under Alternative B, total annual average GHG emissions are 55,183,567 MT (60,829,471 tons), which is about 0.011% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.7% of that under Alternative A. However, total annual emissions are slightly higher than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative B being different from that of Alternative A.

Under Alternative B, the impacts of climate change on sediment resources, humpback chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower would be very similar to those under Alternative A.

4.16.3.3 Alternative C

Under Alternative C, total annual average GHG emissions are 55,195,829 MT (60,842,987 tons), which is about 0.033% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. However, total annual emissions are slightly higher than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative C being different from that of Alternative A.

Under Alternative C, the impacts of climate change on sediment resources would be reduced by climate change resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved, and impacts on humpback chub lessened. The overall number of trout and the number of large trout are expected to be higher than under historic hydrology. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.4 Alternative D (Preferred Alternative)[40]

Under Alternative D, total annual average GHG emissions are 55,200,576 MT (60,848,219 tons), which are about 0.042% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about

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[40] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on climate change or the impacts of climate change on Alternative D.

98.9% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative D being different from that of Alternative A.

Under Alternative D, the impacts of climate change on sediment resources would be reduced by climate change resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout is expected to be higher than under historic hydrology, but the number of large trout would be lower. The impacts on native vegetation would be slightly lower. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.5 Alternative E

Under Alternative E, total annual average GHG emissions are 55,194,171 MT (60,841,159 tons), which are about 0.030% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative E being different from that of Alternative A.

Under Alternative E, the impacts of climate change on sediment resources, humpback chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower would be very similar to those under Alternative D.

4.16.3.6 Alternative F

Under Alternative F, total annual average GHG emissions are 55,222,189 MT (60,872,044 tons), which are about 0.081% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative F being different from that of Alternative A.

Under Alternative F, the impacts of climate change on sediment resources would be reduced by climate change, resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout is expected to be lower than under historic hydrology, but the number of large trout would be higher. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values related to marsh vegetation, but a decrease in those related to overall riparian diversity. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.7 Alternative G

Under Alternative G, total annual average GHG emissions are 55,218,627 MT (60,868,117 tons), which are about 0.074% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.2% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1.

Under Alternative G, the impacts of climate change on sediment resources would be reduced by climate change, resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout, including the number of large trout, is expected to be higher than under historic hydrology. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.17 CUMULATIVE IMPACTS

The CEQ defines a cumulative impact as "the impact on the environment that results from the incremental impact of [an] action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (federal or nonfederal) or person undertakes such other actions" (40 CFR 1508.7). The assessments summarized in this section place the direct and indirect impacts of the alternatives, presented in the preceding sections of Chapter 4, into a broader context that takes into account the range of impacts of all actions within the Colorado River corridor, from Lake Powell and the Glen Canyon Dam downstream and west to Lake Mead, and the broader Colorado River Basin region (e.g., in the case of climate change).

4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting Cumulative Impacts

Past and present (ongoing) actions in the project area have been accounted for in the baseline conditions described for each resource in Chapter 3. Ongoing and reasonably foreseeable future actions considered in the cumulative impact analysis include the projects, programs, and plans of various federal agencies and other entities as described in the following sections. Many of these projects, programs, and plans reflect shared management objectives and cooperation among federal and state agencies, American Indian Tribes, and stakeholders groups that are intended to facilitate more effective and efficient management of the resources in the LTEMP project area. Past, present, and reasonably foreseeable future actions are described in the following sections and summarized in Table 4.17-1.

As described in resource-specific sections in this chapter, the LTEMP alternatives are expected to differ in the types and magnitude of impacts on specific resources. Against the backdrop of past, present, and reasonably foreseeable future actions, however, the incremental effects of the LTEMP alternatives, as described in the following sections, are expected to be relatively minor contributions to cumulative impacts along the Colorado River corridor or within the basin at large.

4.17.1.1 Past and Present (Ongoing) Actions

There are numerous actions documented in decisions, plans, policies, and initiatives that relate directly or indirectly to the operation of Glen Canyon Dam and management of the Colorado River ecosystem (see Section 1.10). These actions are listed below, and establish the current conditions or baseline for the LTEMP.

Glen Canyon Dam 1996 Record of Decision

In 1995, Reclamation published an EIS on the impacts of Glen Canyon Dam operations (Reclamation 1995). The ROD for that EIS (Reclamation 1996) selected the MLFF alternative as the operational regime to be implemented, and in 1996, Reclamation began implementing MLFF. The goal of selecting the preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability. The ROD also specified a number of environmental and monitoring commitments—including adaptive management, monitoring/protection of cultural resources, flood frequency reduction measures, beach/habitat-building flows, a new population of humpback chub, further study of selective withdrawal, and emergency exception criteria—to avoid or minimize environmental impacts from the preferred alternative. The new operating regime was selected to create conditions that promote the protection and improvement of downstream resources while maintaining some flexibility in hydropower production. The ROD estimated that there would be a loss of hydropower benefits (between $15.1 and $44.2 million annually) resulting from selection of MLFF as the future operating regime (Reclamation 1996).

Flaming Gorge Dam Record of Decision

Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the Green River, a major tributary of the Colorado River upstream of Lake Powell, to the extent possible, to achieve the flows and temperatures recommended by participants of the Upper

TABLE 4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable Future Actions and Basin-Wide Trends in the LTEMP Project Area

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions		
Glen Canyon Dam 1996 ROD (Reclamation 1996)	MLFF to reduce daily flow fluctuations and provide high steady releases of short duration at Glen Canyon Dam	In 1995, Reclamation published an EIS on the impacts of Glen Canyon Dam operations (Reclamation 1995). The ROD for that EIS (Reclamation 1996) selected the MLFF alternative as the operational regime to be implemented, and, in 1996, Reclamation began implementing operating criteria under the MLFF alternative. The goal of selecting the preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability.
Flaming Gorge Dam ROD (Reclamation 2006a)	Flow modifications to achieve more natural flows and temperatures (to preserve and protect fish species) in the Green River, a major tributary of the Colorado River	Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the Green River, a major tributary of the Colorado River, to the extent possible, to achieve the flows and temperatures recommended by participants of the Upper Colorado River Endangered Fish Recovery Program to protect and assist in recovery of the populations and designated critical habitat of four endangered fishes, while maintaining all authorized purposes of the Flaming Gorge Unit of the CRSP, including those related to the development of water resources in accordance with the Colorado River Compact. The selected alternative (Action Alternative) was anticipated to result in minimal negative impacts to land use, recreation, mosquito control, and hydropower generation.
Aspinall Unit ROD (Reclamation 2012f)	Flow modifications to simulate more natural spring flows and moderate base flows in the lower Gunnison River, a tributary to the Colorado River	The Aspinall Unit consists of Blue Mesa, Morrow Point, and Crystal Dams, Reservoirs, and Powerplants on the Gunnison River, a tributary of the Colorado River. Reclamation published a ROD in 2012 detailing its decision to modify reservoir operations (beginning in 2012) to avoid jeopardizing endangered fish species and their designated critical habitat by allowing higher and more natural downstream spring flows and moderate base flows in the lower Gunnison River. Under the ROD, the Aspinall Unit is operated to meet specific downstream spring peak flow, duration flow, and base flow targets (at the USGS Whitewater gage), as outlined in the project's FEIS preferred alternative. Base flow is maintained to provide adequate fish passage at the Relands Fish Ladder on the Gunnison River near its confluence with the Colorado River. The selected alternative (Alternative B) ensures that operations at the Aspinall Unit will continue to honor its existing water and power contracts while minimizing environmental impacts; however, minor impacts on hydropower, and on recreation and sport fisheries, as well as a minor reduction in water stored in Blue Mesa Reservoir are anticipated.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Navajo Generating Station (NGS) (TWG 2013; EPA 2014c)	Reductions in air emissions and generation capacity	The NGS is a 2,250-MW coal-fired powerplant located on the Navajo Reservation near Page, Arizona. The powerplant is operated by SRP and serves electric customers in Arizona, Nevada, and California; it also supplies energy to the Central Arizona Project. In 2014, the EPA took final action to require an 80% reduction in NO_X emissions from NGS to reduce its impact on visibility at 11 national parks and wilderness areas. Appendix B of the NGS technical working group agreement proposes several alternatives to help the NGS achieve this goal through a reduction in generation output or other operating strategies. The reduction of generation output at the NGS will reduce levels of NO_X pollutants in the region.
Interim Guidelines (Reclamation 2007a,b)	Determines the annual volume for release from Glen Canyon Dam	Adopted in 2007, these Interim Guidelines would be used each year (through 2025 for water supply determinations and through 2026 for reservoir operating decisions) in implementing the LROC for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. The Interim Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing releases and conserved amounts on predetermined levels in both reservoirs, which would minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin. In addition, the Interim Guidelines established a mechanism for storing and delivering conserved water from Lake Mead, referred to as Intentionally Created Surplus, intended to minimize the severity and likelihood of potential future shortages. Annual volumes may impact recreation economics and water quality in Lake Mead and Lake Powell and water temperatures in the Colorado River; equalization years may increase trout populations below Glen Canyon Dam and increase sandbar erosion. Effects are expected to be independent of the LTEMP alternatives.
Tamarisk Management and Tributary Restoration (GCNP) (NPS 2002a,b, 2014g)	Reduction of tamarisk trees in the project area Increased diversity of native plant species	The NPS continues its efforts to eradicate tamarisk in the GCNP with the goal of restoring more natural conditions inside the canyons along the Colorado River in the GCNP. Over the past 10 years, the NPS has completed work in 130 project areas, removing more than 275,000 tamarisk trees from over 6,000 ac. Although control methods have been effective, overall return of native diversity has been slow. NPS anticipates overall beneficial effects on native vegetation, soil characteristics, water quality, wetlands, wildlife, wilderness, and visitor experience (NPS 2002b). Adverse impacts are expected to be negligible to minor and short in duration (with the exception of microbiotic soil crusts). No significant adverse effects on threatened, endangered, and sensitive species or ethnographic resources are expected. NPS monitors and mitigates the impacts of tamarisk management on an ongoing basis.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Colorado River Management Plan (NPS 2006b,d)	Established visitor capacity based on size and distribution of campsites Established 6.5-month no-motor season Year-round use provides opportunities for a variety of visitor experiences including motorized and non-motorized trips that range from 6 to 25 days	The goal of the CRMP is to protect resources and visitor experience while enhancing recreational opportunities on the Colorado River through the GCNP by establishing visitor capacity based on size and distribution of campsites, overall resource conditions, and visitor experience variables. Recreational use patterns are based on daily, weekly, and seasonal launch limits and seasonal differences in commercial and noncommercial levels. The actions would have beneficial effects on cultural resource sites, traditional cultural properties, ethnobotanical resources, and other elements important to Tribal assessments of canyon environmental health. Beneficial impacts on commercial operators (revenues and profits) and adjacent lands were also anticipated. Impacts on visitors' use and experience were determined to be negligible to moderate and adverse to beneficial, depending on perspective and desired experience. Adverse impacts on natural resources (biological soil crusts, aquatic resources at attraction sites, special status species, and the soundscape) would range from negligible to major.
Backcountry Management Plan (for GCNP) (NPS 1988[a])	Allocates and distributes backcountry and wilderness overnight use in campsites along the Colorado River	The goal of the BCMP is to protect and preserve the park's natural and cultural resources and values and integrity of wilderness character by providing a framework for consistent decision making in managing the park's backcountry, providing a variety of visitor opportunities and experiences for public enjoyment in a manner consistent with park purposes and preservation of park resources and values and providing for public understanding and support of preserving fundamental resources and values for which Grand Canyon was established. Proposed actions would address both beneficial and adverse effects to: wildlife populations and habitat by minimizing human-caused disturbances and habitat alteration, minimizing impacts to native vegetation, reducing exotic plant species spread, and preserving fundamental biological and physical processes; enhancing wilderness character and values; developing and implementing an adaptive management process that includes monitoring natural, cultural, and experiential resource conditions and responding when resource degradation has resulted from use levels; preserving and protecting natural soil conditions by minimizing impacts to soils from backcountry recreational activities; minimizing adverse chemical, physical, and biological changes to water quality in tributaries, seeps, and springs; and preserving cultural resource integrity and condition.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Abandoned Mine Lands Closure Plan (NPS 2010b)	Closure of mine openings	The NPS will address health and safety hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at 16 AMLs in GCNP. Closure of mine openings[b] would have a long-term beneficial impact on historic structures by protecting mine features from vandalism; however, impacts associated with closure construction activities (installing gates, grates, or cupolas or moving earth, rocks, or tailings piles), while localized, would range from negligible to mostly minor, with some possible moderate adverse (i.e., measurable and perceptible) effects. Beneficial impacts would also be expected on bats and other wildlife by providing protection from disturbance, although NPS notes that closure construction could have minor long-term adverse effects, especially to other wildlife that use the openings for nesting, denning, or shade (effects would be partially mitigated by avoiding closing mine features that are used by a listed species). Because several AML sites are located near trails and river access points in GCNP, they are easily accessible by visitors (although no safety incidents have been documented). Impacts of AML closure, therefore, are expected to be beneficial overall because they would reduce the likelihood of injury from visitor access. Visitors wishing to experience bats and other wildlife, however, may incur localized short-term negligible to minor adverse effects (especially during closure construction when small areas would be closed to visitors). NPS notes that other sites would remain open to visitors, thus affording other opportunities to experience bats and wildlife and mitigating these impacts.
Fire Management Plan (GCNP) (NPS 2012f)	Reduction of wildfire risk in GCNP Ecosystem Restoration	The NPS manages wildland fire risk in GCNP using an adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels reduction, community assistance, and accountability. Implementation of the plan meets the park goals and objectives for managing park resources and visitor experiences, as identified in the General Management Plan (NPS 1995). It also supports the objects of the Resource Management Plan (NPS 1997). This plan may have beneficial or adverse impacts related to fire reduction, such as decreased runoff of sediments, decreased flooding, maintaining or restoring habitat in uplands.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Uranium Mining and Public Lands Withdrawal (DOI 2012b)	Withdrawal of federal lands in the Grand Canyon region from location and entry Continued exploration and mining on state and private lands	In January 2012, the Secretary of Interior withdrew from location and entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern Arizona for a 20-year period. The purpose of the land withdrawal is to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse effects related to locatable mineral exploration and development (i.e., uranium mining). It would have no effect on the exploration and development of any non-federal lands within its exterior boundaries; the withdrawal area would remain available for the development of federal leasable and salable minerals. Active exploration for uranium on state and private lands in the region would not be affected by the withdrawal. Potential impacts of uranium mining are currently difficult to quantify because of the uncertainties of subsurface water movement, radionuclide migration, and biological exposure pathways. Based on its study of groundwater near historic uranium mining sites in northern Arizona, the USGS concluded the likelihood of adverse impacts on water resources (from water use and degradation or impairment) is likely to be low, but if water resources were affected, the risk to the greater ecosystem, Tribes, and tourists could be significant (Bills et al. 2010; DOI 2012b). Other potential (but localized) impacts include impacts on aquatic and other biota and habitats associated with drainages in the event of accidental releases of hazardous materials into local drainages.
Comprehensive Fisheries Management Plan (below Glen Canyon Dam) (NPS 2013e)	Potential stocking of sterile rainbow trout in Lees Ferry Translocation of native fish species Removal of high-risk nonnative fish from areas important for native fish Beneficial use of all nonnative fish removed Implementation of an experimental adaptive strategy for evaluating the suitability of razorback sucker in western portions of the Grand Canyon	The main purpose of the plan is to maintain a thriving native fish community within GCNP while also maintaining a highly valued recreational trout fishery community in the Glen Canyon reach. The actions would have a beneficial effect on native and endangered fish populations, as well as visitor experience (by avoiding quality decline of the rainbow trout fishery), and no significant adverse effect on public health, public safety, or threatened or endangered species. They would, however, contribute to long-term ethnographic resource cumulative impacts resulting from fish management (specifically euthanizing fish), which constitutes an adverse effect under Section 106 of the NHPA. This effect would be mitigated to the extent possible through an MOA between the NPS, SHPO, and Tribes (NPS 2013h).

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Lower Colorado River Multi-Species Conservation Program (DOI 2005)	Management of take permits (while conserving critical habitat and protecting threatened and endangered species)	The program is a cooperative species conservation effort between federal and non-federal entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water diversions and power production while optimizing opportunities for future water and power development and to provide the basis for incidental take permits while conserving critical habitat and working toward the recovery of threatened and endangered species. Potential beneficial impacts to special status species in Lower Basin.
Reasonably Foreseeable Future Actions		
Special Flight Rules in the Vicinity of GCNP, AZ (14 CFR Part 93, Subpart U)	Reduction of noise in GCNP	Rules to be established to substantially restore natural quiet at GCNP in accordance with the National Parks Overflights Act of 1987 (PL 100-91). Would establish a system of routes, altitudes, flight allocations and flight free zones in the air space in and around GCNP.
Lake Powell Pipeline Project (UBWR 2015)	Construction/operation of pipeline and penstock Construction/operation of hydropower stations Construction/operation of transmission lines Increased water withdrawal from Lake Powell (adjacent to Glen Canyon Dam)	The Utah State legislature has authorized the UBWR to build a pipeline to transfer water from Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in southwestern Utah. The proposed pipeline is currently being evaluated for potential effects on water storage in Lake Powell and related resources, the availability of water for downstream users, habitat conditions, and aquatic species and resources, including sport fisheries (UBWR 2011a,b).

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Reasonably Foreseeable Future Actions (Cont.)		
Grand Canyon Escalade (Confluence Partners, LLC 2012a)	Construction/operation of multiple elements (tramway, riverwalk, road, parking lots, and buildings) Increased visitation up to 10,000 people per day Trespass into GCNP Increased jobs and gross revenues (to the Navajo Nation)	A developer, Confluence Partners, LLC, working with the Navajo Nation has proposed the 420-ac development project on the Grand Canyon's eastern rim, on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking lots. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural resources (e.g., impacts on Little Colorado River and other humpback chub habitats; wildlife disturbance due to noise and loss of habitat) and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in impacts on the local economy through increased tourism and job creation.
Red Gap Ranch Pipeline (City of Flagstaff City Council 2013)	Increased groundwater withdrawal from the C-aquifer on the Coconino Plateau Construction/operation of multiple elements (wells, roads, pipelines, and a treatment facility)	In anticipation of a future water supply shortfall, the City of Flagstaff has purchased property on the Red Gap Ranch on which it plans to develop new municipal wells to augment its current supply. The wells would withdraw up to 8,000 ac-ft of groundwater each year from the C-aquifer on the Coconino Plateau. A NEPA review, currently underway, is evaluating the impacts of groundwater withdrawal from the aquifer on base flow feeding the Little Colorado River, Clear Creek, and Chevelon Creek, which ultimately flow into the Colorado River. These withdrawals could affect habitats of humpback chub and other native fish, especially in the Little Colorado River. The NEPA review is also evaluating the impacts of groundwater conveyance on biological and cultural resources on the Red Gap Ranch property.
Page-LeChee Water Supply Project (NPS 2009b)	Construction/operation of water intakes and pumping station Construction/operation of a conveyance pipeline	The Page-LeChee would improve the existing water supply system for the city of Page and the LeChee Chapter of the Navajo Nation. It would increase the capacity of water already drawn from Lake Powell; it would include water intakes, a pumping station, and a conveyance pipeline located on the GCNRA. While the proposal would allow higher diversions of water from Lake Powell, actual consumptive use would continue to be subject to the city's contract with the Bureau of Reclamation.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Reasonably Foreseeable Future Actions (Cont.)		
Four Corners Power Plant (FCPP) and Navajo Mine Energy Project (OSMRE 2015a, b)	Reduced NO_x and PM pollutants emissions Coal-mining activities and associated land disturbance and air emissions	The FCPP, located just north Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), historically consisted of five pulverized coal-burning steam electric generating units with a total generating capability of 2,100 MW and other ancillary facilities. The proposed lease amendment would extend the life of the powerplant to 2041. Under the proposed alternatives, air emissions would not exceed NAAQS and deposition impacts with 50 km (31 mi) of the FCPP are expected to be negligible. The Arizona Public Service Company closed three of the five generation units (Units 1, 2, and 3) at the end of 2013, and over the next couple of years is scheduled to install SCR controls on the remaining two units (Units 4 and 5) to reduce NO_x and PM pollutants that contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas, including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b). Development of a new coal mine would result in land disturbance and air emissions.
Clean Power Plan Proposed Rule (EPA 2014b)	Reduced CO_2 emissions	The Clean Power Plan Proposed Rule would reduce atmospheric carbon by limiting the CO_2 emissions from existing fossil-fuel fired powerplants in the United States. The draft plan would establish state-by-state carbon emissions rate reduction targets with the aim of reducing emissions from the power sector to about 30% below 2005 levels by 2030 (EPA 2014b). The EIA (2015) estimates the proposed rule would result in a reduction of U.S. power sector CO_2 emissions to about 1,500 million MT/yr by 2025 (levels not seen since the early 1980s). The U.S. Supreme Court granted a stay in February 2016, halting implementation of the plan.
Human Activities Affecting Climate		
	Increased temperatures (air and surface water) Increased variability in precipitation and stream flows Drought conditions and water loss (through evaporation and evapotranspiration) Increased risk of wildfires Decreased snowpack and stream flows (due to less late winter precipitation and snowpack sublimation)	The southwest is already experiencing the effects of climate change, with the decade from 2001 to 2010 being the warmest on record (Garfin et al. 2014; World Meteorological Organization 2014; NAS 2007). Precipitation trends are more variable across the region, but drought-induced water shortages in the Colorado River Basin are a growing concern. Changes in temperature and precipitation patterns could take a toll on the diversity of plant and animal species (e.g., widespread loss of trees due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and an increased risk of heat stress and disruption to electric power generation. The recreational economy could also be affected by a shorter snow season and reduced streamflow (Garfin et al. 2014).

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Human Activities Affecting Climate (Cont.)		
	Seasonal shifts in snowmelt and high stream flows (to earlier in the year)	
	Increased flooding potential (due to earlier snowmelt)	
	Decreased spring and summer runoff (due to decreased snowpack)	
	Lowered reservoir levels (Lakes Powell and Mead)	
	Increased agricultural water demand (due to increased temperatures)	
	Reduced agricultural yields	
	Insect outbreaks	
	Increased production rates of algae and invertebrates	
	Spread of nonnative species adapted to warmer temperatures	
	Increased wildfires	
	Reduced plant and animal diversity (widespread tree mortality)	
	Heat threats to human health	

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[a] New BCMP expected to be implemented with ROD in 2016.

[b] NPS notes that except for backfilling, most closure types would be reversible, thereby reducing the impacts of closure on those sites eligible for the *National Register* (NPS 2010b).

Colorado River Endangered Fish Recovery Program to protect and assist in recovery of the populations and designated critical habitat of four endangered fishes, while maintaining all authorized purposes of the Flaming Gorge Unit of the CRSP, including those related to the development of water resources in accordance with the Colorado River Compact. The selected alternative (Action Alternative) was anticipated to result in minimal negative impacts to land use, recreation, mosquito control, and hydropower generation (Reclamation 2006a).

Aspinall Unit Record of Decision

The Aspinall Unit, managed and operated by Reclamation (in cooperation with various other federal agencies), consists of Blue Mesa, Morrow Point, and Crystal Dams, Reservoirs, and Powerplants on the Gunnison River, a tributary of the Colorado River upstream of Lake Powell. It was originally authorized by the Colorado River Storage Project Act of 1956. In 2012, Reclamation published a ROD that details the decision to modify reservoir operations (beginning in 2012) to avoid jeopardizing endangered fish species and their designated critical habitat by allowing higher and more natural downstream spring flows and moderate base flows in the lower Gunnison River (Reclamation 2012f). The selected alternative (Alternative B) ensures that operations at the Aspinall Unit will continue to honor its existing water and power contracts while minimizing environmental impacts; however, minor impacts on hydropower, and on recreation and sport fisheries, as well as a minor reduction in water stored in Blue Mesa Reservoir are anticipated (Reclamation 2012f).

Navajo Generating Station

The Navajo Generating Station (NGS) is a 2,250-MW coal-fired powerplant located on the Navajo Reservation near Page, Arizona. The powerplant is operated by SRP and serves electric customers in Arizona, Nevada, and California. It also supplies energy to the Central Arizona Project, which diverts water from the Colorado River at Lake Havasu near Parker to agricultural land Indian Tribes in southern Arizona (SRP 2016; Reclamation 2016). In 2014, the EPA took final action to require an 80% reduction in NO_X emissions from NGS to reduce its impact on visibility at 11 Class I federal areas (national parks and wilderness areas) (EPA 2014c). Appendix B of the NGS technical working group (NGSTWG 2013) proposes several alternatives to help the NGS achieve this goal through a reduction in generation output (e.g., ceasing generation on one NGS unit) or other operating strategies. The reduction of generation output at the NGS will reduce levels of NOx pollutants in the region.

Interim Guidelines for Coordinated Operation of Lake Powell and Lake Mead

In 2005, spurred by a multi-year drought, decreasing system storage, and growing demands for Colorado River water, the Secretary directed Reclamation to work with the Basin States to develop additional strategies for addressing the coordinated management of the reservoirs of the Colorado River system. In response, Reclamation began to develop and adopt interim operational guidelines that would address the operation of Lake Powell and Lake Mead during drought and low-reservoir conditions. Adopted in 2007, these Interim Guidelines would be used each year (through 2025 for water supply determinations and through 2026 for reservoir operating decisions) in implementing the LROC for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. The ROD (2007b) did not modify the authority of the Secretary to determine monthly, daily, hourly, or instantaneous releases from Glen Canyon Dam.

The completed Interim Guidelines determine the availability of Colorado River water for use in the Lower Basin, on the basis of Lake Mead's water surface elevation, as a way to conserve reservoir storage and provide water users and managers with greater certainty regarding the reduction of water deliveries during drought and other low-reservoir conditions. The Interim Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing releases and conserved amounts on predetermined levels in both reservoirs, which would minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin. In addition, the Interim Guidelines established a mechanism for storing and delivering conserved water from Lake Mead, referred to as "intentionally created surplus," intended to minimize the severity and likelihood of potential future shortages. Nothing in this LTEMP EIS is intended to affect or will affect future decisions that may be made regarding the implementation of the LROC after the Interim Guidelines expire in 2026.

Drought conditions in the Colorado River Basin between 2000 and 2007, coupled with increased demands for Colorado River water supplies, resulted in decreased reservoir storage in the basin from 55.8 million ac-ft in 1999 (94% of capacity) to 32.1 million ac-ft in 2007 (54% of capacity). The interim guidelines incorporate three main elements: (1) shortages to conserve reservoir storage; (2) coordinated operation of Lakes Powell and Mead on the basis of specified reservoir conditions to minimize shortages in the Lower Basin and avoid the risk of curtailments of use in the Upper Basin; and (3) water conservation in the Lower Basin to increase retention of water in Lake Mead. The interim guidelines presented in Section XI of the ROD (Reclamation 2007b) define "normal conditions" in Lake Mead as reservoir levels above elevation 1,075 ft AMSL and below elevation 1,145 ft AMSL. They quantify surplus and shortage conditions against these levels and define apportionments to Lower Basin states on this basis.

Tamarisk Management and Tributary Restoration Project at Grand Canyon National Park

The NPS continues its efforts to eradicate tamarisk in side canyons, tributaries, developed areas, and springs above the pre-dam water level in GCNP (NPS 2002a,b, 2014g). Tamarisk is a nonnative shrub that was introduced to the United States in the 19th century as an erosion control agent. Since its introduction, the plant has spread throughout the west and has caused major changes to natural ecosystems. The shrub reached the GCNP in the 1920s and by the time Glen Canyon Dam was completed in 1963, it had become a dominant riparian zone species along the Colorado River. The NPS's ongoing goal is to restore more natural conditions inside canyons along the river in GCNP and to prevent further loss or degradation of existing native biota. To this end, restoration biologists use an adaptive strategy to manage and control tamarisk in the

GCNP. Control measures involve a combination of mechanical and chemical methods tailored to site-specific conditions and plant size. These include pulling, cutting to stump level, applying herbicide, and girdling (leaving the dead tree in place for wildlife habitat) (NPS 2014g).

The tamarisk leaf beetle (*Diorhabda* spp.) was not intentionally introduced in GCNRA or GCNP, but was discovered in 2009 near Navajo Bridge and at RM 12, and at several locations, including Lees Ferry, in 2010. It is currently found throughout Glen and Grand Canyons (Section 3.6.2). The beetle causes early and repeated defoliation of tamarisk, eventually resulting in mortality. Although the beetle has been associated with widespread defoliation of some tamarisk communities along the river, its long-term effects on tamarisk abundance and distribution in Glen and Grand Canyons is not currently known.

Colorado River Management

The CRMP specifies the actions that NPS follows to protect resources and visitor experience while enhancing recreational opportunities on the Colorado River through GCNP (NPS 2006a,b). The CRMP describes management goals for two geographic sections of the Colorado River: (1) Lees Ferry to Diamond Creek, and (2) Diamond Creek to Lake Mead. The selected action for the Lees Ferry to Diamond Creek section (RM 0 to 226) defines mixed motor/no motor seasons and reduces the maximum group size for commercial groups. It establishes use patterns based on daily, weekly, and seasonal launch limits, provides year-round noncommercial use and a 6.5 month non-motorized use period during the shoulder and winter seasons. Management of the Lower Gorges section from Diamond Creek to Lake Mead (RM 226 to 277) involves cooperation between the NPS and the Hualapai Tribe, and provides opportunities for shorter whitewater and smoothwater trips (NPS 2006b).

Backcountry Management Plan

The Backcountry Management Plan defines the concepts, policies, and operational guidelines NPS follows to manage visitor use and protect natural resources in the backcountry and wilderness areas of the GCNP (NPS 1988). The objectives of the Backcountry Management Plan are to provide a variety of backcountry recreational visitor opportunities that are compatible with resource protection and visitor safety. The plan supports the objectives of the CRMP and is currently undergoing revision. A Draft EIS on the proposed plan was issued in late 2015 (NPS 2015b).

Abandoned Mine Lands Closure Plan

In 2010, the NPS finalized an EA that evaluated methods to correct health and safety hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at 16 abandoned mine lands (AMLs) in GCNP (NPS 2010b). The resources affected by AML closure are historic structures (mine features such as adits, shafts, and cairns, among others) and districts, bats and other wildlife (including federally listed species and species of management concern), visitor experience (including health and safety), and wilderness.

Fire Management at Grand Canyon National Park

The NPS manages wildland fire risk in GCNP through its Fire Management Program, as detailed in its Fire Management Plan (NPS 2012d). The Fire Management Plan employs an adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels reduction, community assistance, and accountability. Implementation of the plan meets the park goals and objectives for managing park resources and visitor experiences, as identified in the General Management Plan (NPS 1995). The Fire Management Plan also supports the objectives of the Resource Management Plan (NPS 1997). These include protecting human health and safety and private and public property; restoring and maintaining park ecosystems in a natural and resilient condition; interpreting and educating Tribes, stakeholders, and the public about the importance of the natural fire regime; and promoting a science-based program that relies on current and best-available information, as described in Table 3.2 of NPS (1995).

Uranium Mining and the Northern Arizona Withdrawal of Public Lands

Uranium mineralization in the Grand Canyon region is associated with geologic features called breccia pipes. A breccia pipe is a cylindrical, vertical mass of broken rock (breccia) that typically measures tens of meters across and hundreds of meters vertically. There are 1,300 known or suspected breccia pipes in the Grand Canyon region (Spencer and Wenrich 2011). Development of uranium minerals associated with breccia pipes dates back to the 1940s. By the late 1980s, more than 71 breccia pipes had been found to contain ore-grade rock (DOI 2012b). As of 2010, over 23 million lb of uranium (U_3O_8) had been produced from nine breccia pipes (Spencer and Wenrich 2011); the estimated mean undiscovered uranium endowment for the region is about 933.6 million lb (Otton and Van Gosen 2010)

In January 2012, the Secretary of Interior withdrew from location and entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern Arizona for a 20-year period (DOI 2012b). The withdrawal includes 684,449 ac of federal land administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of GCNP (South Parcel). The purpose of the land withdrawal is to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse effects related to locatable mineral exploration and development (i.e., uranium mining). The withdrawal would have no effect on the exploration and development of any non-federal lands within its exterior boundaries (with the exception of about 23,993 ac of split estate lands where locatable minerals are owned by the federal government), and the withdrawal area would remain available for the development of federal leasable and salable minerals (e.g., oil and gas leases and sand and gravel permits). The public land laws would still apply (DOI 2012b).

Although 3,156 mining claims predate BLM's notice of withdrawal in 2009, most of these did not have valid existing rights at the time of the notice and, therefore, cannot be developed during the withdrawal period. The BLM estimates that 11 mines, including four existing uranium mines, could still be developed under the full withdrawal, a level similar to that in the 1980s when the high price of uranium spurred interest in mining (DOI 2012b). Arizona State land parcels and private lands in the region could also be developed (NPS 2013k). Thus, uranium mining, while reduced, will continue throughout the withdrawal period.

Active exploration for uranium in the region is currently focused on state and private lands located within the Cataract Canyon/Havasu Creek surface and groundwater basins, to the south of GCNP. These lands are adjacent to the Havasupai Reservation, Hualapai Reservation, and the Kaibab National Forest, and are operated near the Boquillas Ranch and other private lands owned by the Navajo Nation (NPS 2013k).

Comprehensive Fisheries Management below Glen Canyon Dam

The NPS is implementing its Comprehensive Fisheries Management Plan for all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam. The plan was developed in coordination with the Arizona Game and Fish Department, the FWS, Reclamation, and the USGS GCMRC; its purpose is to maintain a thriving native fish community within GCNP, while also maintaining a highly valued recreational trout fishery in the Glen Canyon reach, defined as the 16.5 mi of river downstream from Glen Canyon Dam on the Colorado River in the GCNRA, including Lees Ferry and the mouth of the Paria River (NPS 2013e, 2013h).

The plan's management goals for the Colorado River and its tributaries in GCNP are as follows:

1. Meet or exceed population and demographic goals for the appropriate GCNP recovery unit for existing ESA-listed fish species, maintain self-sustaining populations, and restore distribution of those species to the extent practicable;

2. Maintain or enhance viable populations of existing native fish and restore native fish communities and native fish habitat in GCNP to the extent practicable;

3. Restore self-sustaining populations of extirpated fish species, including Colorado pikeminnow, razorback sucker, bonytail, and roundtail chub, as appropriate and to the extent feasible (if feasibility studies determine each species can be reasonably restored without impacting existing ESA-listed species);

4. Foster meaningful Tribal relations and integrate Tribal knowledge and perspectives into park management decisions and practice; and

5. Prevent further introductions of nonnative (exotic) aquatic species, and remove when possible, or otherwise contain, individuals or populations of nonnative species already established in GCNP.

The plan's management goals for the Colorado River and Paria River in GCNRA are as follows:

1. Maintain a highly valued recreational rainbow trout fishery with minimal emigration of rainbow trout downstream to GCNP;

2. Restore and maintain healthy, self-sustaining native fish communities; native fish habitat; and the important ecological role of native fish to the extent possible;

3. Foster meaningful Tribal relations and integrate Tribal knowledge and perspectives into park management decisions and practices; and

4. Prevent further introductions of nonnative (exotic) species.

Lower Colorado River Multi-Species Conservation Program

The Lower Colorado River Multi-Species Conservation Program (LCRMSCP) implements and coordinates the Secretary of the Interior's statutory responsibilities under the ESA (DOI 2005). The program is a cooperative species conservation effort between six federal agencies (Reclamation, BIA, NPS, BLM, WAPA, and the FWS) and numerous non-federal entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water diversions and power production while optimizing opportunities for future water and power development (lead agency: Reclamation) and to provide the basis for incidental take permits (lead agency FWS) while conserving critical habitat and working toward the recovery of threatened and endangered species as well as reducing the likelihood of additional species being listed. Measures to mitigate the impacts of the incidental take of species covered under the Program are contained in its Habitat Conservation Plan (LCRMSCP 2004). The Habitat Conservation Plan and other program information are available at http://www.lcrmscp.gov/index.html.

4.17.1.2 Reasonably Foreseeable Future Actions

Special Flight Rules in the Vicinity of Grand Canyon National Park

The NPS will establish new rules to substantially restore natural quiet at GCNP in accordance with the National Parks Overflights Act of 1987 (P.L. 100-91). The rules would create a system of routes, altitudes, flight allocations, and flight-free zones in the air space in and around GCNP.

Lake Powell Pipeline Project

In 2006, the Utah State legislature passed the Lake Powell Pipeline Development Act to authorize the Utah Board of Water Resources (UBWR) to build a pipeline to transfer water from Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in southwestern Utah. At full development, the pipeline is expected to annually deliver up to 82,000 ac-ft to Washington County Water Conservancy District and 4,000 ac-ft to Kane County Water Conservancy District. The proposed project would consist of (1) building and operating 139 mi of 69-in. diameter pipeline and penstock, 35 mi of 30-in. to 48-in. diameter pipeline, and 6 mi of 24-in. diameter pipeline; (2) a combined conventional peaking and pumped storage hydropower station; (3) five conventional in-pipeline (booster) hydropower stations; and (4) transmission lines. The booster pumping stations along the length of the pipeline would provide the 2,000-ft lift needed to move the water over the high point within the Grand Staircase-Escalante National Monument. From the high point, water would flow through a series of hydroelectric turbines to make use of the 2,900-ft drop in elevation from the high point to the end of the pipeline in St. George (UBWR 2015; FERC 2011). The Lake Powell intake would be located near the south end of the reservoir adjacent to Glen Canyon Dam (UBWR 2011a). UBWR plans to have its licenses, permits, and ROD issued sometime in 2015 so construction can begin in 2020 (water delivery would not begin until 2025) (UBWR 2015).

Grand Canyon Escalade

Private developers have proposed to the Navajo Nation, a 420-ac development project, known as the Grand Canyon Escalade, on the Grand Canyon's eastern rim on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The development would include a 1.4-mi-long, eight-person tramway (gondola) to transport visitors 3,200 ft from the rim to the canyon floor. On the rim, the development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking for cars and RVs. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk (with an elevated walkway) along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in beneficial impacts to the local economy through increased tourism and job creation.

Red Gap Ranch Pipeline

In 2006, Reclamation completed a study that projected a water supply shortfall of about 3,370 ac-ft/yr for the City of Flagstaff (and other towns in Coconino County) by the year 2050 (Reclamation 2006b). To address its shortfall, the City of Flagstaff has purchased property on the Red Gap Ranch (about 34 mi to the east), on which it plans to develop new municipal wells to augment its current supply. The wells would withdraw up to 8,000 ac-ft of groundwater each year from the C-aquifer (on the Coconino Plateau) and send it via pipeline to the City (City of

Flagstaff City Council 2013). Because the pipeline crosses federal land and is partially funded with federal dollars, the proposed project is currently undergoing a NEPA review (EA). The scope of the EA is to evaluate the impacts of groundwater withdrawal on the base flow that feeds the Little Colorado River, Clear Creek, and Chevelon Creek (which ultimately feed the Colorado River), as well as the impacts the conveyance of groundwater (including the construction of pipelines, roads, and a treatment facility) could have on biological and cultural resources on the Red Gap Ranch property.

Page-LeChee Water Supply Project

The Page-LeChee water supply project is a water supply facility providing domestic water supply for the city of Page and the LeChee Chapter of the Navajo Nation (NPS 2009b). The proposed project would improve the existing system (consisting of three pumps operating at 3,050 gpm) and increase the capacity of water already drawn from Lake Powell; it would include water intakes, a pumping station, and a conveyance pipeline located on the GCNRA (from Lake Powell to a tie-in point on the existing system near U.S. 89 between the Glen Canyon rim and the water treatment plant in Page). Although the proposal would allow higher diversions of water from Lake Powell, actual consumptive use would continue to be subject to the city's contract with Reclamation.

Four Corners Power Plant and Navajo Mine Energy Project

The Office of Surface Mining Reclamation and Enforcement (OSMRE) has completed a final EIS for the lease amendment with the Navajo Nation that would extend the life of the Four Corners Power Plant (FCPP) to 2041 (OSMRE 2015a, b). The FCPP, located just north of Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), historically consisted of five pulverized coal-burning steam electric generating units with a total generating capability of 2,100 MW and other ancillary facilities, including Morgan Lake and Morgan Lake Dam, fly ash storage silos and bottom ash dewatering bins, three switchyards, an intake canal, and access road (OSMRE 2015b). The Arizona Public Service Company closed three of the five generation units (Units 1, 2, and 3) at the end of 2013, and over the next couple of years is scheduled to install selective catalytic reduction (SCR) controls on the remaining two units (Units 4 and 5) to reduce NO_X and particulate matter (PM) pollutants that contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas, including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b). The proposed action would also include the renewal of the transmission line right-of-way that connects the powerplant to the power grids in Arizona and New Mexico and the development of a new 5,600-ac mine area, the Pinabete Mine Permit area, to supply coal to the powerplant for up to 25 years (beginning July, 2016). The Pinabete Mine area is a surface coal mining and reclamation operation located near the existing Navajo Mine in San Juan County, New Mexico (OSMRE 2015c), and would result in land disturbance and air emissions in the project area.

EPA's Clean Power Plan Proposed Rule for Existing Power Plants

The Clean Power Plan Proposed Rule is being developed by the U.S. Environmental Protection Agency (EPA) under Section 111(d) of the Clean Air Act (CAA) to reduce atmospheric carbon by limiting the CO_2 emissions from existing fossil-fuel fired powerplants in the United States. The final plan, released in October 2015, establishes state-by-state carbon emissions rate reduction targets with the aim of reducing emissions from the power sector to about 30% below 2005 levels by 2030 (EPA 2014b, 2015c). The EIA (2015) estimates the proposed rule would result in a reduction of power sector CO_2 emissions to about 1,500 million MT/yr by 2025, levels not seen since the early 1980s. The U.S. Supreme Court stayed implementation of the Clean Power Plan on February 9, 2016, pending judicial rule (EPA 2016).

4.17.2 Climate-Related Changes

The southwest is already experiencing the effects of climate change (Garfin et al. 2014). The decade from 2001 to 2010 was the warmest on record, with temperatures almost 1.1°C higher than historic averages (Garfin et al. 2014; World Meteorological Organization 2014). Precipitation trends are more variable across the region, but drought-induced water shortages in the Colorado River Basin are a growing concern, prompting federal and state agencies, Tribes, and other stakeholders to develop adaptation and mitigation strategies to address imbalances between water supply and demand in the coming years (Garfin et al. 2014; NAS 2007; Reclamation 2007b, 2012c). Section 4.16 provides a discussion of climate change as related to the LTEMP.

Higher temperatures in the Colorado River Basin have resulted in less precipitation falling and being stored as snow at high elevations in the Upper Basin (the main source of runoff to the river), increased evaporative losses, and a shift in the timing of peak spring snowmelt (and high streamflow) to earlier in the year (NAS 2007; Christensen et al. 2004; Jacobs 2011). These effects in turn have exacerbated competition among users (farmers, energy producers, urban dwellers), as well as effects on ecological systems, during a time when due to a rapidly rising population water demand has never been higher (Garfin et al. 2014).

As discussed in the *Colorado River Basin Water Supply and Demand Study* (Reclamation 2012e), the general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (due to lower precipitation), greater evaporation and evapotranspiration losses (due to higher temperatures), and increased demand (due to increased population size). Combined, these factors increase the probability and likely duration of delivery shortages in coming decades. It has been estimated that the shortfall created by future supply and demand imbalances could range from 2.3 to 4.1 maf per year, during any given deficit period (Reclamation 2012e). When climate change considerations are taken into account, this value increases to around 7.4 maf per year during the deficit period (Reclamation 2012e). In 2007, DOI adopted interim guidelines (Reclamation 2007b) to allocate shortages and specify modifications to the apportionments to the Lower Basin states in the event of water shortage conditions at Lake Mead (see section above).

Changes in temperature and precipitation patterns attributed to climate change could also take a toll on the region's rich diversity of plant and animal species (e.g., widespread loss of trees due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and an increased risk of heat stress and disruption to electric power generation (during summer heat waves). The recreational economy could also be affected by a shorter snow season and reduced streamflow (Garfin et al. 2014). Such effects are likely to continue well into the foreseeable future (NAS 2007). These changes would be the same under all LTEMP alternatives and would be unaffected by the alternatives.

4.17.3 Cumulative Impacts Summary by Resource[41]

The following sections discuss the past, present, and reasonably foreseeable future actions, including the LTEMP alternatives, that could contribute to cumulative impacts on resources within the project area. Table 4.17-2 provides a summary of these contributions by resource area.

The physical presence and design constraints of Glen Canyon Dam have created a new baseline condition for resources within the Colorado River corridor, from Lake Powell and the dam downstream and west to Lake Mead. Current safety and design requirements limit flow through the dam to no more than 45,000 cfs, about 53% of its historical maximum flow. Management of water flow within the river system is also constrained by the various treaties, decrees, statutes, regulations, contracts, and agreements that are collectively known as the Law of the River. Recent drought conditions in the Colorado River Basin have necessitated further regulation (i.e., the 2007 Interim Guidelines) to allocate shortages and reduce apportionments to the Lower Basin states during periods of declining reservoir storage at Lake Mead. The water supply and demand equation is further stressed by the challenges of increasing demand in the seven Basin States (due to a rising population) and the temperature variability and drought attributed to climate change, which are projected to reduce flows into the foreseeable future.

As described in resource-specific sections in this chapter, the LTEMP alternatives are expected to differ in the types and magnitude of impacts on specific resources. Against the backdrop of past, present, and reasonably foreseeable future actions, however, the incremental effects of the LTEMP alternatives, as described in the following sections, are expected to be relatively minor contributions to cumulative impacts along the Colorado River corridor or within the basin at large.

4.17.3.1 Water Resources

Although LTEMP alternatives differ in monthly, daily, and hourly flows, all alternatives must be consistent with and subject to the Law of the River as identified in GCPA

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[41] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's cumulative impact.

TABLE 4.17-2 Summary of Cumulative Impacts and Incremental Contributions under LTEMP Alternatives

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Water Resources	Colorado River between Glen Canyon Dam and Lake Mead; Lakes Powell and Mead	Projected future changes in flow due to increased water demand (as a result of population growth and development), and decreased water supply, drought, and increased water temperature attributed to climate change could be the greatest contributors to adverse impacts on Colorado River flows, storage in Lakes Powell and Mead, and water quality (temperature and salinity). The 2007 Interim Guidelines and related water conservation efforts, should provide more predictability in water supply to users in the Basin States (especially the Lower Basin) through 2026, and may also benefit water temperature and water quality in Lakes Powell and Mead. Future water depletions from Lake Powell including those from the proposed Lake Powell Pipeline Project and Page-LeChee Project could affect availability of water for release from Glen Canyon Dam.	The proposed action is consistent with the 2007 Interim Guidelines for annual water deliveries. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions. With the exception of Alternative B, the LTEMP alternatives would result in slightly greater summer warming and a slightly increased potential for bacteria and pathogens along shorelines.
Sediment Resources	Colorado River between Glen Canyon Dam and Lake Mead; inflow deltas in Lake Mead	Potential future hydrology in the Colorado River (as determined by the 2007 Interim Guidelines), including the effects of climate change, could affect tributary sediment delivery (supply), fine sediment transport, sandbar formation, and lake delta formation over the long term. Glen Canyon Dam and Lake Powell trap most of the mainstem Colorado River sediment supply (post-dam sediment supplies less than 10% of the pre-dam supply). Implementation of HFEs could result in an improvement in sandbar building.	LTEMP alternatives are expected to improve sediment conditions to varying degrees by conserving sediment and building sandbars at higher elevations. Alternatives with the most HFEs (Alternatives C, D, E, F, and G) have the highest sandbar building potential. Alternative A has the lowest sandbar building potential. The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Natural Processes	Colorado River ecosystem in Glen, Marble, and Grand Canyons	Projected future changes in flow due to increased water demand (as a result of population growth and development) and decreased water supply (and sediment supply), drought, and increased water temperature attributed to climate change would contribute to adverse impacts on natural processes through changes in Colorado River flows, sediment supply, and temperature. Implementation of HFEs could result in an improvement in sandbar building. Tamarisk control and fisheries management actions could improve natural processes by restoring native species.	Compared to Alternative A, Alternatives C, D, F, and G are expected to increase sediment conservation, increase the stability of nearshore habitats, and provide slightly warmer water temperatures. The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Aquatic Ecology	Colorado River between Glen Canyon Dam and Lake Mead	Aquatic resources would be affected by changes in flow due to increased water demand (as a result of population growth and development); decreased water supply, drought, and increased water temperature attributed to climate change; and other foreseeable actions (related to fish management and uranium mining). The potential for urban and agricultural runoff also increases with population growth, producing adverse effects on water quality, which could ultimately affect aquatic biota and habitat. Drought conditions (and actions such as the Lake Powell pipeline project) would result in lower reservoir elevations and benefits to aquatic resources associated with warmer release temperatures. Warmer water temperatures, however, could also result in adverse effects if they increase the distribution of nonnative species adapted to warm water (e.g., fish parasites). 2007 Interim Guidelines determine annual volume and equalization years may increase trout production and river temperature both of which may impact humpback chub populations. Uranium mining could also have adverse (though local) effects on aquatic biota and habitats associated with ephemeral drainages (in the event of an accidental release of hazardous materials). Translocation of native fish species (humpback chub) from the Little Colorado River to other tributaries within the Grand Canyon would have a beneficial (protective) impact on aquatic resources.	Compared to Alternative A, Alternative D would have lower trout numbers, slightly higher humpback chub numbers, and increased food base productivity. Alternatives with higher fluctuation levels (Alternatives B and E) have lower trout numbers and slightly higher humpback chub numbers than Alternative A, but less nearshore habitat stability and aquatic productivity. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Vegetation	Riparian zone along the Colorado River between Glen Canyon Dam and Lake Mead	Lower regional precipitation with climate change would result in a shift to more drought-tolerant species in the New High Water Zone; those in the Old High Water Zone would continue to decline. Drought conditions would favor nonnative tamarisk (which is tolerant of drought stress). However, tamarisk control efforts by the NPS and possibly the effects of the tamarisk leaf beetle and splendid tamarisk weevil would increase tamarisk mortality and improve conditions for native shrubs over time. Feral burros contribute to impacts on riparian vegetation in the Old High Water Zone (by reducing vegetation and decreasing species diversity); recreational visitors may also contribute to vegetation loss and the introduction of exotic plant species.	Most alternatives, including Alternative A, result in a decrease in native community cover and wetlands. Alternative D is the only alternative that results in an overall improvement in vegetation. The program's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Wildlife	Colorado River corridor between Glen Canyon Dam and Lake Mead	Cumulative impacts on aquatic resources and riparian vegetation (as described in the above entries) affect riparian and terrestrial wildlife. Wildlife may also be affected by other future actions and basin-wide trends. Increased water demand and lower flows downstream of Glen Canyon Dam could stress riparian and wetland vegetation, affecting both wildlife habitats and the wildlife prey base. Warmer discharges (attributed to climate change) would likely increase algae and invertebrates, increasing the prey base for some species. Vegetation management could adversely affect birds in the short term, but are expected to provide benefits in the long term. Wildlife disturbance could result from various actions, including uranium mining, the Grand Canyon Escalade Project, and recreational activities (hiking, rafting, fishing, and camping). Habitat loss is a concern for those projects involving the construction of roads, effluent ponds (mining), and buildings.	Most alternatives would have little effect on most wildlife species. Alternatives with more fluctuations, and less-even monthly release volumes (Alternatives A and B), would have greater impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic life stages. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Cultural resources	Cultural sites within Glen and Grand Canyons	Cultural resources (primarily archaeological sites) are in an ongoing state of deterioration due to natural erosive processes or, in some cases, human causes related to the presence and operation of Glen Canyon Dam or park visitation. Visitor traffic along the Colorado River can result in deterioration of sites as artifacts exposed by erosion are moved or removed from the site. These effects are somewhat mitigated through enforcement of NPS's Colorado River Management Plan and Backcountry Management Plan in GCNP (with similar enforcement in GCNRA). The effects of climate change on landscape features containing archaeological remains are unclear. Ongoing dam operations may affect sediment availability for site stabilization in GCNP and lowered reservoir levels may affect archaeological sites along shorelines in GCNRA and LMNRA.	Alternatives with extended-duration HFEs (Alternatives D and G) could adversely impact terraces that support cultural resources in Glen Canyon. Alternatives with more HFEs (e.g., Alternatives C, D, E, F, and G) could provide for greater protection of sites by providing more sand for wind transport to these sites. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Tribal resources	Glen, Marble, and Grand Canyons	Many Tribes regard the Canyons as sacred space, the home of their ancestors, the residence of the spirits of their dead, and the source of many culturally important resources. Development related to projects like the Lake Powell Pipeline and uranium mining in the region, as well as fish/vegetation management practices, have ongoing adverse impacts on Tribe members. Actions and basin-wide trends affecting aquatic life, vegetation, and wildlife (as described above) would also affect resources of value to Tribes.	All alternatives except Alternative F include either mechanical removal of trout or TMFs and may have an adverse impact to Tribes. Alternatives that include vegetation treatments (all action alternatives), and alternatives that improve vegetation conditions (Alternatives B and D), could lead to a more natural riparian ecosystem and provide a benefit. No alternative would affect Tribal water rights. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Recreation, visitor use and experience	Colorado River and associated recreational sites between Glen Canyon Dam and Lake Mead	The HFE protocol has had a beneficial effect on camping and beach access (and therefore visitor use and experience) because it has a direct effect on sediment transport and deposition. Other actions taken by the NPS, as described in various management plans (tamarisk management, GCNP backcountry, noise and special flight rules, fire), also benefit visitor use and experience. The CRMP (which regulates boating and rafting) and the Comprehensive Fisheries Management Plan and Non-Native Fish Control Program are protective of natural/cultural resources and also have long-term beneficial effects on recreation and visitor experience. Warming water temperatures (and reduced flows below Glen Canyon dam) attributed to climate change could affect the health of the trout fishery below the dam, thus contributing to adverse cumulative impacts on recreation related to the trout fishery.	Most alternatives would result in a reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G). The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Wilderness	Colorado River and associated recreational and wilderness sites between Glen Canyon Dam and Lake Mead	The HFE protocol and other actions taken by the NPS, as described in various management plans (the CRMP, tamarisk management, GCNP backcountry, noise and special flight rules, fire) would benefit wilderness values and experience (although noise and visual effects associated with some actions diminish these values over the short term). The Grand Canyon Escalade would contribute to adverse impacts on visitors seeking solitude or a wilderness experience due to its visual and noise effects and the presence of infrastructure, all of which are incompatible with the character of GCNP. Basin-wide effects related to climate change (e.g., reduced water availability) could diminish wilderness values and experience by reducing opportunities for solitude.	Disturbance from non-flow actions would occur under all alternatives; the most crowding at rapids would occur under Alternative E; alternatives with greater fluctuations (e.g., Alternatives A, B, and E) could affect wilderness character. The program's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Visual resources	Shorelines and waters of the Colorado River between Glen Canyon Dam and Lake Mead; shorelines of Lakes Powell and Mead; and the general landscape in the project area	Projected future declines in reservoir levels due to increased water demand, decreased water supply, the planned Lake Powell Pipeline project, and drought attributed to climate change could increase the likelihood of exposure of calcium carbonate rings and sediment deltas in Lakes Powell and Mead. Infrastructure associated with the Lake Powell Pipeline project (pipeline, facilities, viewing platforms, and transmission lines), uranium mining, vegetation changes, and elements of the Grand Canyon Escalade development would also add to visual contrast and noticeable changes in the existing landscape.	LTEMP alternatives do not vary with respect to their impacts on visual resources. the proposed action’s contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Hydropower	Utilities and their customers who purchase power generated by Glen Canyon Dam WAPA, Upper Colorado Basin Fund, environmental programs funded by CRSP power revenues; Upper Basin State apportionment-funded projects	Operating criteria imposed by the 1996 ROD for Glen Canyon Dam to comply with the Grand Canyon Protection Act have placed multiple restrictions on the variability of water released from the dam, thus restricting dam operational flexibility. Under the current operating regime (MLFF), fluctuations in release rates, ramp rates, and maximum hourly increases/decreases are restricted and the maximum release rate for power generation is limited to 25,000 cfs. Maximum releases above 25,000 cfs occur through bypass tubes to achieve a constant release rate. Bypassing water around generators produces no energy, which can result in additional purchases of replacement power. Increased demand for electricity in the service territories of the eight largest WAPA customer utilities and planned retirement of existing powerplant generating capacity would require an estimated 4,820 MW of new capacity to be built over the next 20 years. Changes in operations due to environmental concerns at other generating stations (the Aspinall Unit and Flaming Gorge Dam) have also resulted in reductions in generating capacity at these facilities, necessitating the purchase of replacement capacity from other sources and increasing wholesale power rates. Changes at NGS to meet air emissions requirements may result in a reduction in generation output at the facility and its contribution to power in the Western Interconnection. This could result in excess transmission capacity within the Western Interconnection.	LTEMP alternatives vary with respect to hydropower production, hydropower capacity, and retail rates, and therefore cumulative impacts. Alternatives with higher fluctuation levels (Alternatives A, B, D, and E) achieve higher values of generation and capacity and lower impacts on retail rates than do alternatives with steadier flows (Alternatives C, F, and G), especially if more water is released in the high-demand months of July and August. Alternatives A and B would have the least effect on the value of generation, the value of capacity, and retail rates, while Alternatives F and G would have the highest. However, the proposed action's contribution to cumulative impacts would be small compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Socioeconomics and environmental justice	Six-county region in the vicinity of the Colorado River between Lakes Powell and Mead; recreational resources, including Lake Powell, Lake Mead, and the Grand Canyon (Colorado River)	Projected future changes in reservoir levels and river flow due to increased water demand, decreased water supply, and drought attributed to climate change could be the greatest contributors to adverse impacts on the recreational use values associated with fishing, day rafting, and whitewater boating. The Grand Canyon Escalade would likely increase recreational visitation and expenditure rates along the Colorado River. The annual release volume from Glen Canyon Dam, as determined by the 2007 Interim Guidelines, also affects recreation economics. NPS regulates the number of boating trips (specified in the CRMP and the Comprehensive Fisheries Management Plan). Therefore, regional economics of these activities are not expected to change in the foreseeable future.	LTEMP alternatives result in relatively minor changes in use value and economic activity associated with reservoir and river recreation, and in residential retail rates. Environmental justice issues are associated with alternatives that incorporate frequent trout control actions (Alternatives C, D, and G), or result in increased economic impacts on Tribes associated with the cost of electricity (Alternatives F and G). The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Air quality and climate change	GCNP and the 11-state Western Interconnectionion region	The construction of new (and the renewal of existing) fossil fuel-fired powerplants to meet increased energy demands from population and industrial growth in the region, coupled with drought conditions brought on by climate change (which increase the potential for wildfires and dust storms), could increase visibility degradation in the foreseeable future. The natural scattering of light would continue to be the main contributor to visibility degradation (haze) in the region, including GCNP. Other significant contributors would include wildfires, controlled burns, windblown dust, and emissions from metropolitan areas (manufacturing, coal-fired powerplants, and combustion sources like diesel engines). Hydropower generation at Glen Canyon Dam does not generate air emissions; however, dam operations can affect ambient air quality by causing a loss of generation that is offset by generation from coal, natural gas, or oil units. Under baseline operations (Alternative A), emissions of SO_2 and NO_x generated by powerplants affected by Glen Canyon Dam operations would be about 9.9% and 3.0% of the total emissions over the Western Interconnectionion region, respectively. Air quality impacts due to emissions under the other alternatives would be negligible because they would be only slightly increased or decreased relative to the baseline. Increases in GHG emissions associated with changes in operations under LTEMP alternatives would be negligible. The EPA's Clean Power Plan Proposed Rule (currently stayed by the U.S. Supreme Court) would have a beneficial impact on the air quality in the region by mandating reductions in CO_2 emissions from fossil fuel-fired powerplants. The closure of three coal-burning units at the FCPP would reduce levels of NO_x and PM pollutants that contribute to regional haze and visibility issues in the GCNP. The reduction of generation output at the NGS to meet air emissions requirements will reduce levels of NO_x in the region.	LTEMP alternatives are expected to have negligible differences with respect to their impacts on air emissions including GHGs. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

Section 1802(b). As a consequence, the impacts of alternatives do not vary in their contribution to cumulative impacts on water supply and delivery.

Current water quality conditions and characteristics of Lake Powell (Section 3.2.2.1), Colorado River below Glen Canyon Dam (Section 3.2.2.2), and Lake Mead (Section 3.2.2.3) reflect the effects of past and present (ongoing) actions. Before Glen Canyon Dam was constructed, the river was characterized by wide natural fluctuations in water quality characteristics (e.g., temperature, salinity, turbidity, and nutrients). In the post-dam era, these variations are moderated and the river has seen an overall improvement in water quality. Future water quality would likely be affected most by increased water demand and climate change. Although most alternatives would likely result in a slightly increased potential for bacteria and pathogens along shorelines, the contribution of continued operations under the LTEMP to cumulative impacts on water quality is expected to be negligible regardless of which alternative is selected.

As the population in the Basin States grows and expands, municipal, industrial, and agricultural water demand continues to increase. In its 2013 study, Reclamation concluded that the total consumptive use and loss (i.e., surface water and groundwater depletions and evaporative losses) for the Arizona portion of the Upper Colorado River Basin (covering about 6,900 mi^2) was 35,037 ac-ft, more than half of which is water pumped directly from Lake Powell and used by the Navajo Generating Station (Reclamation 2014e).

Urban runoff, industrial releases, and municipal discharges are considered some of the leading nonpoint sources of contaminants to surface waters (EPA 2004). Areas of intensive agriculture can have an adverse effect on the water quality as a result of the salinity, nutrients, pesticides, selenium, and other trace elements that are common constituents in agricultural runoff. As a result, water management and efficient water use become important variables in the Colorado River supply and demand equation (Beckwith 2011). The 2007 Interim Guidelines, and related water conservation efforts, should provide more predictability in water supply to users (especially in the Lower Basin) through 2026.

The general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (e.g., lower precipitation) and greater losses (e.g., evapotranspiration associated with higher temperatures and increased demand from the growing population). Climate change is expected to result in more frequent and severe drought conditions in the Southwest. Meeting increasing water needs (e.g., the Lake Powell Pipeline project and the Page-LeChee water supply project) will likely lead to lower reservoir levels in Lake Powell, which may already be affected by increased evaporation associated with higher air temperatures. As discussed in Section 4.2.2, decreasing the elevation of Lake Powell can lead to warmer water discharges from Glen Canyon Dam and increased water temperatures downstream.

4.17.3.2 Sediment Resources

The construction and presence of Glen Canyon Dam has affected Glen, Marble and Grand Canyons by (1) reducing the sediment supply, and by (2) reducing the annual peak flows.

Among the actions considered under LTEMP, HFE releases (which are highest under Alternatives C, D, E, F, and G) have the greatest impact on sediment resources (and sandbar building potential), although variability in hydrology or sediment supply from tributary inputs has a greater impact than HFEs. Cumulative impacts that affect this variability in hydrology and sediment supply (such as climate change) have the potential to affect sediment resources in the future.

It has been estimated that the post-dam sand supply to Marble Canyon is less than 10% of the pre-dam supply (Topping et al. 2000a; Topping, Rubin, Nelson et al. 2000; Wright, Schmide et al. 2008), with the majority of the sediment evacuation between the dam and Phantom Ranch (RM 87) occurring during the three decades following dam construction. The reduced sediment supply would move downstream at different rates in the various LTEMP alternatives, but sediment supply to Marble and Grand Canyons would not differ among the alternatives. The 1996 ROD modifications to the flow regime resulted in benefits for the building and retention of sandbars.

Future climate change implications on sediment resources are highly variable and cannot be accurately quantified. Conceptually, climate change can affect the sediment resource in two ways: by changing the hydrology in the drainage area upstream of Glen Canyon Dam, and by changing the hydrology in the drainage area downstream of Glen Canyon Dam, especially in the drainage area of primary sediment contributors such as the Paria River and the Little Colorado River. A drier future hydrology in these drainage areas could decrease the availability of sand in Marble and Grand Canyons.

4.17.3.3 Natural Processes

Cumulative impacts on natural processes (water flow, water temperature, and sediment supply) reflect those discussed under water resources (Section 4.17.3.1) and sediment resources (Section 4.17.3.2). Although some of the LTEMP alternatives could affect these resources (e.g., potential sandbar growth through implementation of HFE releases, which is greatest under Alternatives C, D, E, F, and G), the incremental effects of the alternatives are not anticipated to contribute significantly to cumulative impacts on natural processes along the Colorado River corridor or within the basin at large. Implementation of HFEs could result in an improvement in sandbar building over the long term. Tamarisk control and fisheries management actions could improve natural processes by restoring native species. Climate change (and its effects on water flow, water temperature, and sediment supply), however, would likely have a greater effect on natural processes than any of the LTEMP alternatives.

4.17.3.4 Aquatic Ecology

Section 3.5.1 describes the current conditions of the aquatic food base in the Colorado River downstream of Glen Canyon Dam. The current state of the aquatic food base reflects the effects of past and present (ongoing) actions; Section 4.5.3 discusses potential impacts of the various LTEMP alternatives. The aquatic food base may also be affected by other reasonably foreseeable actions, particularly climate change, dam modification, water use, introduction of nonnative species, and uranium mining.

Population growth, industrial development, and the warming associated with climate change will act in concert to increase demand for water (Schindler 2001). The potential for urban and agricultural runoff also increases with population growth, producing adverse effects on water quality, which could ultimately affect aquatic biota and habitat. Climate change is also expected to result in more frequent and severe drought conditions in the Southwest, which will continue to tax water supplies. Combined with increased evaporation associated with higher temperatures, meeting water needs would lead to lower reservoir levels in Lake Powell. The Lake Powell Pipeline Project would also contribute to lower Lake Powell reservoir elevations (FWS 2011c). Lowering of Lake Powell elevations can lead to warmer water discharges from Glen Canyon Dam. The Red Gap Ranch Pipeline, which would withdraw groundwater contributing to the base flow of the Little Colorado River, could reduce habitat availability and suitability in the Little Colorado River with subsequent adverse effects on humpback chub and designated critical habitat, although the magnitude of these impacts have not been quantified.

Warmer water temperatures would likely increase production rates of algae and invertebrates (Woodward et al. 2010; FWS 2011c). Lower levels of Lake Powell may also result in increases in the composition and density of zooplankton downstream of Glen Canyon Dam, because waters would be withdrawn closer to the surface (Reclamation 1995). However, warmer temperatures, particularly in winter, may allow many invertebrate species to complete their life cycles more quickly (Schindler 2001). For example, if stream temperatures are raised by only a few degrees in winter, many aquatic insects that normally emerge in May or June may emerge in February or March and face death by freezing or be prevented from mating because of being inactivated by low air temperatures. In addition, increases in stream temperatures may cause an exaggeration in the separation of the emergence of males and females (e.g., males may emerge and die before females emerge) (Nebeker 1971). Temperatures above the optimum can lead to the production of small adults and lower fecundity (Vannote and Sweeney 1980).

Warmer water temperatures can expand the distribution of nonnative species adapted to warmer temperatures. This includes fish parasites such as the Asian tapeworm, anchor worm, and nonnative crayfish. Increased zooplankton due to climate change may increase abundance of cyclopoid copepods. All cyclopoid copepod species appear to be susceptible to infection by, and therefore serve as intermediate hosts for, the Asian tapeworm (Marcogliese and Esch 1989). Crayfish can prey on fish eggs and larvae and can diminish the abundance and structure of aquatic vegetation such as filamentous algae through grazing (FWS 2011c). Nonnative crayfish are present in Lake Powell (northern or virile crayfish [*Orconectes virilis*]) and Lake Mead (red swamp crayfish [*Procambarus clarkii*]). Warmer temperatures may allow the crayfish to expand into the mainstem of the Colorado River either downstream of Lake Powell or upstream of Lake Mead.

As discussed in Section 3.5.1, some nonnative species introductions occurred in order to supplement the aquatic food base (e.g., *Gammarus*, snails, and midges); while accidental introductions have occurred via fish stocking and recreational fishing, often with detrimental effects on both lower trophic levels or fish species (e.g., the New Zealand mud snail and parasitic trout nematode [*Truttaedacnitis truttae*]). The quagga mussel (*Dreissena bugensis*), which is established in Lake Powell, may develop viable populations in the mainstem of the Colorado River, at least within the Glen Canyon reach.

Concern has been raised about the diatom *Didymosphenia geminata* ("didymo") becoming established in the Colorado River. High-density blooms of didymo are frequent in rivers directly below impoundments. In these river reaches, stable flows and fairly constant temperatures favor development of large masses of didymo (see Spaulding and Elwell 2007). Didymo can form nuisance benthic growths that extend for more than 1 km and persist for several months (Spaulding and Elwell 2007). Mayflies, stoneflies, caddisflies, and dragonflies have an inverse relationship with didymo coverage, while midges and aquatic worms dominate didymo-covered areas (Larson and Carreiro 2008). Nevertheless, the presence of didymo has been associated with increased periphyton biomass and increased invertebrate densities and richness (Kilroy et al. 2009; Gillis and Chalifour 2010). Given the large amounts of non-nutritious stalk material present on stream substrates in affected areas, didymo is predicted to have deleterious effects on native fish, especially those that inhabit benthic habitats, consume benthic prey, and nest beneath or between cobbles (see Spaulding and Elwell 2007). Didymo is present in waters from 4 to 27°C (39 to 81°F) (Spaulding and Elwell 2007), so warming would not be a factor in its occurrence in the Colorado River. However, development of didymo blooms likely requires both low mean discharge and variation in discharge. Scouring events usually remove didymo stalk material from substrates (Kirkwood et al. 2007).

Uranium mining peaked in the 1980s in the Grand Canyon region, but there is now a renewed interest due to increases in uranium prices. Increased uranium mining (on state and private lands) could increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Uranium, other radionuclides, and metals associated with uranium mines can affect the survival, growth, and reproduction of aquatic biota.

Aquatic biota and habitats most likely to be affected during mine development and operation are those associated with small, ephemeral, or intermittent drainages. Impacts on aquatic biota and habitats from the accidental release of regulated or hazardous materials into ephemeral drainages would be localized and small, especially if a rapid response to a release is undertaken. The accidental spill of uranium ore into a permanent stream or river such as Kanab Creek would potentially pose a localized short-term impact on the aquatic resources. However, the potential for such an event is extremely low. Most ore solids would settle in the waterbody within a short distance from a spill site (Edge Environmental, Inc. 2009). It is expected that expedient and comprehensive cleanup actions would be required under U.S. Department of Transportation regulations and that an emergency response plan would be in place for responding to accidents and cargo spills (Edge Environmental, Inc. 2009). Overall, the potential for impacts on aquatic biota from an accidental spill would be small to negligible. Spencer and Wenrich (2011) estimated that if an ore load is washed into the Colorado River and is pulverized and dissolved (a scenario that is extremely unlikely to impossible), the uranium concentration in the river would increase from the current 4.0 ppb to only 4.02 ppb (undetectable against natural variations). Predicted no chemical effect concentrations for aquatic vascular plants, aquatic invertebrates, and fish are ≥5.0 ppb; the lowest chronic concentrations are well above that concentration (see Hinck et al. 2010). For these reasons, the impacts from uranium mining on aquatic biota in the Colorado River or its major tributaries would be expected to be localized and would not be expected to reduce the viability of affected resources.

The incremental effects of the LTEMP alternatives on fish are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Examination of the various hydrologic traces used to model effects of alternatives on aquatic resources indicated that hydrology (i.e., whether a 20-year trace was drier or wetter on average) had a greater influence on the model results than the operational differences among alternatives. Similarly, climate change has the potential to have greater effects on fish resources than any of the alternatives because of its direct influences on hydrologic patterns. For example, more frequent droughts and warmer atmospheric temperatures have the potential to result in greater increases in the temperature of water being released from the dam than the operational actions being considered, and this in turn may improve thermal suitability for humpback chub, humpback chub aggregations, and native fish. However, any subsequent benefits may be offset by increased abundance and expansion of nonnative fish and aquatic fish parasites. There are a number of other actions being taken within the Colorado River Basin that could also contribute to significant cumulative effects on fish populations or fish communities. For example, actions to increase the number of self-sustaining populations of humpback chub within the basin (e.g., translocation of humpback chub from the Little Colorado River to other tributaries within the Grand Canyon) have the potential to increase overall numbers of humpback chub and could provide some level of protection against catastrophic events in the Little Colorado River that could greatly reduce or eliminate the population of humpback chub in the Grand Canyon.

4.17.3.5 Vegetation

In addition to effects of releases from Glen Canyon Dam and NPS's experimental vegetation treatment program, factors that would impact riparian plant communities include the tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil (*Coniatus* spp.), which occur along much of the Colorado River below Glen Canyon Dam. By late 2012, the tamarisk leaf beetle had been found in many locations in the Grand Canyon, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Tamarisk leaf beetle is not expected to have impacts on populations of other plant species, such as native shrubs (Dudley and Kazmer 2005). Fire management policies for GCNP include fuel reduction by removal of dead woody material as well as fire suppression; however, riparian areas are generally avoided (NPS 2012d).

The replacement of tamarisk by other species and the timing of replacement would be affected by flow characteristics as well as site-specific factors. The potential reduction in the dominance of tamarisk in many areas and the decrease in total area of tamarisk-dominated communities along the Colorado River could result in an increase in native species or, more likely, other nonnative species, especially where soils have high nitrogen levels (Hultine et al. 2010; Shafroth et al. 2005, Shaforth, Brown et al. 2010; Belote et al. 2010; Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012; Bateman et al. 2013). Many nonnative species are already present along portions of the Colorado River and Lake Mead (Table 4.6-5). Short-term changes in nutrient dynamics in the riparian ecosystem could also occur with increased activity of tamarisk leaf beetles, with subsequent effects on the future development of native or nonnative communities (Uselman et al. 2011). Soil seed banks may contain a high diversity of species and would potentially influence subsequent plant community composition; however, the regrowth of native species may be slow (Reynolds and Cooper 2011; Belote et al. 2010).

As discussed in Section 4.6, hydrologic conditions have a greater effect on native community types in the Fluctuation Zone and New High Water Zone than do the operational characteristics of the LTEMP alternatives. Within each alternative, the occurrence of flows with significant effects on riparian vegetation, such as extended high flows and extended low flows, are determined in large part by the inflow to Lake Powell as a result of hydrologic variation (Section and 4.2). Other events, such as spill flows (flows >45,000 cfs that would necessitate use of the spillway) could have pronounced effects on riparian vegetation, but these too result from hydrologic variation and not characteristics of the alternatives. However, with forecasting capabilities currently used by the Bureau of Reclamation, it is unlikely that spill flows would occur in the future. Within a year, under any alternative, monthly operations may be increased or decreased based on changing annual runoff forecasts, and application of the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

Feral burros contribute to cumulative impacts on riparian vegetation, especially vegetation in the Old High Water Zone. Researchers documented vegetation impacts from feral burros as early as 1974, noting vegetation destruction and decreases in species diversity. These impacts, along with impacts on soils, remain visible on the landscape today with very little vegetation recovery (Leslie 2004).

Visitation from commercial and private river trips, as well as backcountry hikers and anglers, also can affect vegetation. Visitors have created trails and added to the loss of vegetation in upland and Old High Water Zone areas. Administrative actions such as tamarisk eradication projects and archaeological site monitoring programs can also contribute to vegetation impacts. The intentional or unintentional spread of exotic plant species by humans coming into the area of effect contributes to the current levels of impacts along the Colorado River corridor. This can have localized, adverse, short- or long-term, year-round effects on vegetation by visitors in the riparian zone, and has effects in camping areas, trails, and in popular visitation areas (NPS 2006b).

Riparian ecosystems are expected to be affected by long-term changes in the climate across the Colorado River watershed. Under a climatic trend of lower precipitation, there would likely be fewer years with extended high flows and an increase in the number of years with extended low flows under any of the alternatives. It is also possible that, with lower regional precipitation, there could be fewer sediment-triggered HFEs if the Paria River delivers less sediment. Riparian plants in the Old High Water Zone are expected to continue to decline. The New High Water Zone would tend to experience a shift toward more drought-tolerant species, such as arrowweed and mesquite. Tamarisk is tolerant of drought stress, and has an advantage over native species that require access to groundwater, such as cottonwood and willow, in areas where water tables are lowered. Thus, tamarisk may be maintained under drier climate conditions, although recruitment events may be limited and, as noted above, effects of defoliation may greatly affect tamarisk-dominated communities. Communities that require a shallow water table or relatively frequent inundation, such as marsh, shrub wetland, and cottonwood-willow woodland, would likely decline.

Natural events, such as floods inside canyons and rockfalls, scour vegetation; this can add to the loss of diverse and intact native vegetation and contribute to the spread of invasive, exotic plant species. In addition, as noted in Section 3.6.2, years with unusually high inflow into Lake Powell, such as 1983, may result in emergency dam releases greater than 45,000 cfs that would have major and lasting effects on vegetation (Mortenson et al. 2011; Ralston 2012).

The effects of the LTEMP alternatives on riparian vegetation communities are relatively small compared to the effects of other factors, especially future hydrology. For this reason, the incremental effects of the alternatives on native and nonnative plant species are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Most alternatives, including Alternative A, are expected to result in a decrease in native community cover and wetlands. Alternative D is the only alternative that is expected to result in an overall improvement in vegetation.

4.17.3.6 Wildlife

Section 3.7 describes the current condition of wildlife in the Grand Canyon, which reflects the effects of past and present cumulative impacts; Section 4.7 discusses the potential impacts the various LTEMP alternatives may have on wildlife. Because the assessment of impacts on wildlife is based partly on an evaluation of impacts on the aquatic food base, fish (Section 4.5.2), and riparian vegetation (Section 4.6), cumulative impacts on those resources will also result in cumulative impacts on wildlife. Wildlife may also be affected by other reasonably foreseeable future actions and basin-wide trends contributing to cumulative impacts (Sections 4.17.1.2 and 4.17.2), particularly water use, climate change, vegetation management, AML closure, fire, trout management, introduction or spread of nonnative species, human-associated noise and visual disturbance (e.g., from recreation), and uranium mining.

Population and industrial growth, coupled with climate change, will act in concert to increase water demand in the region (Schindler 2001) and lower flows downstream of Glen Canyon Dam. This could stress existing riparian and wetland vegetation, leading to plant community alterations that would affect both wildlife habitats and the wildlife prey base. Climate change would not affect all wildlife species uniformly. Some species would experience distribution contractions and likely shrinking populations while other species would increase in suitable areas and thus possibly experience increases in population numbers. Generally, the warmer the current range is for a species, the greater the projected distributional increase (or lower the projected loss) will be for that species due to climate change (van Riper et al. 2014).

Lowering of Lake Powell elevations can lead to warmer water discharges from Glen Canyon Dam. Warmer water temperatures would likely increase production rates of algae and invertebrates (Woodward et al. 2010; also see FWS 2011c) leading to increases in the prey base for some wildlife species such as amphibians, lizards, waterfowl, insectivorous songbirds, and bats.

Riparian vegetation management activities (e.g., removal of nonnative plants and planting of native plants) would modify the cover, stratification, and distribution of plant communities along the Colorado River. Eradication of tamarisk could affect birds by altering prey availability, increasing nest abandonment and predation, and reducing the quantity of riparian habitat available to breeding birds (Paxton et al. 2011). In the long term, riparian vegetation management may diversify riparian habitats and establish a more productive wildlife community. Additional factors that could affect riparian wildlife habitat include the tamarisk leaf beetle and splendid tamarisk weevil, which occur along much of the Colorado River below Glen Canyon Dam and result in defoliation and mortality of tamarisk (Section 4.17.3.4). Widespread tamarisk mortality would likely result in a net loss in riparian habitat for at least a decade or more (Paxton et al. 2011). It seems unlikely that the effects of large-scale defoliation in areas dominated by tamarisk will be compensated for by use of tamarisk beetles as a food resource by birds (Puckett and van Riper 2014).

The highly flammable tamarisk has created a fire hazard previously absent along the river. This threatens breeding bird populations, as well as other wildlife. In addition, if native or mixed habitat stands burn, monotypic tamarisk will likely recolonize, eliminating the crucial structure necessary for southwestern willow flycatchers and other nesting birds (e.g., thermal buffering through shading becomes insufficient and will be further exacerbated by warming climate trends) (Schell 2005).

The quagga mussel (*Dreissena rostriformis bugensis*), which is currently established in Lake Powell, may develop viable populations in the mainstem of the Colorado River, at least within the Glen Canyon reach. An established population of quagga mussels may increase the prey base available to diving ducks. Warmer temperatures may allow crayfish inhabiting Lake Mead and Lake Powell to expand into the mainstem of the Colorado River, providing an additional prey item for some wildlife species.

In the past, uranium mining led to localized peregrine falcon nest failures in areas such as Kanab Canyon and its multiple side canyons, where numerous mining claims existed (Payne et al. 2010). Although 684,449 ac of federal land administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of GCNP (South Parcel) would be withdrawn from locatable mineral exploration and development (i.e., uranium mining), increased uranium mining on non-federal (state and private) lands remaining open to mining could locally affect wildlife habitat (e.g., habitat loss and fragmentation) and increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Edge habitat associated with uranium mines and associated access roads may provide habitat for brown-headed cowbirds (Payne et al. 2010), which are brood parasites of songbirds. Grazing and recreation, including use of commercial pack-stock, also increase brown-headed cowbird populations (Schell 2005). Habitat loss from uranium mines and associated access roads could affect the distribution and movement of big game mammals (e.g., elk, mule deer, bighorn sheep, and mountain lions), and potentially increase their mortality from vehicle collisions or poaching

(Payne et al. 2010). There could be a potential contaminant exposure issue associated with amphibians (or other wildlife) attracted to uranium mine effluent ponds (Payne et al. 2010). In general, any impacts on wildlife from uranium mining would be localized and should not affect the viability of affected resources, especially with the use of best management practices to control mine discharges and proper mine reclamation.

The Grand Canyon Escalade Project and its associated facilities near the confluence of the Little Colorado River could cause both a localized loss of wildlife habitat and source of wildlife disturbance due to human presence. Wildlife species in the Grand Canyon are currently exposed to various sources of manmade noise ranging from human conversation to aircraft flyovers. The potential effects of noise on wildlife include acute or chronic physiological damage to the auditory system, increased energy expenditures, physical injury incurred during panicked responses, interference with normal activities (e.g., feeding), and impaired communication (AMEC Americas Limited 2005). The response of wildlife to noise would vary by species; physiological or reproductive condition; distance; and the type, intensity, and duration of the disturbance. Regular or periodic noise could cause adjacent areas to be less attractive to wildlife and result in a long-term reduction in use by wildlife in those areas. Responses of wildlife to disturbance often involve activities that are energetically costly (e.g., flying or running), altering their behavior in a way that might reduce food intake, communication, and nesting (Hockin et al. 1992; Brattstrom and Bondello 1983; Cunnington and Fahrig 2010; Francis et al. 2009; Maxell 2000).

Recreational activities such as hiking, rafting, fishing, and camping can result in disturbance to wildlife. For example, hikers, rafters, anglers, and researchers can disturb bald eagles; however, southwestern willow flycatchers are not apparently sensitive to rafts or boats passing their breeding sites, but people moving through occupied habitat can disturb the birds or impact a nest (Holmes et al. 2005). Impacts on reptiles and amphibians can include occasional opportunistic collecting or harassment by recreationists. As demand for reptiles in the pet trade increases and collectors seek new sources of supply, many national parks are experiencing problems with illegal reptile collection, especially of rattlesnakes (NPS 2014h). Recreationists can affect birds and other wildlife by removing or modifying vegetation within both the new and old high-water zones (e.g., for campsites and trails) (NPS 2005a).

During winter 1990–1991, more eagles were detected in reaches with low human use compared to reaches with high to moderate human use between Glen Canyon Dam and the Little Colorado River. No eagles were found within 1 km of intensively used areas near Lees Ferry and Navajo Bridge. Repeated flushing by bank fishermen, hikers, or boats could have caused wintering eagles to avoid reaches heavily used by anglers (Brown and Stevens 1997). Winter camping, especially in important eagle activity areas, can disturb bald eagles and has the potential to seriously disrupt a wintering eagle concentration (Sogge and Tibbitts 1994).

The effects of the LTEMP alternatives on wildlife are relatively small compared to the effects of other factors, especially future hydrology, and are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Most alternatives would have little effect on most wildlife species. Alternatives with more fluctuations, and less even monthly release volumes (Alternatives A and B), would have greater impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic life stages.

4.17.3.7 Cultural Resources

The proposed action is not expected to significantly change the ongoing cumulative impacts on historic properties. Past dam operations resulted in transformations to the environment that may contribute to the nature, severity, and rate of erosive forces having the potential to act upon and influence the integrity of these historic properties. The past action primarily affecting these resources was the construction and operation of the Glen Canyon Dam and the resulting loss of sediment in the river channel below the dam.

The river immediately downstream from Glen Canyon Dam was intentionally scoured in 1965 during a series of high-pulse flows. These pulse flows, coupled with other dam operation activities, transformed the pre-dam Glen Canyon, which had plentiful sand, native species, and active natural processes, to a present-day Glen Canyon that is incised, narrowed, and armored (Grams et al. 2007). The Glen Canyon Dam has prevented sediment-laden extreme high flows that occurred periodically in the past and allowed for both deposition and erosion at higher elevations, as well as extreme low flows that exposed sandbars and allowed wind transport to higher elevation terraces.

For GCNRA, these transformations include bed incision and reduction in the base level of erosion, sediment evacuation and exposure of terrace faces, and changes in gully type and formation processes. The degree to which these transformations may contribute to impacts on historic properties remains poorly understood, and is the subject of ongoing research. For GRCA, these transformations are primarily tied to loss of low-elevation sandbars and the degradation of the pre-dam river terraces that were home to peoples for the past 10,000 years.

In addition, the effects from visitors remain a persistent issue, although not overarching. The proposed action pertains to the operation of Glen Canyon Dam and does not alter any policies concerning visitor use of the river. The concern over visitor effects is exacerbated by erosion, which continues to expose additional portions of archaeological sites. The more artifacts are exposed at a site, the more opportunities exist for a visitor to pick up an artifact and move it. Only education can make visitors aware of the need to leave the artifacts as they lie.

Historic properties in the APE remain in a continual state of deterioration. The erosive forces that created the Grand Canyon continue to operate throughout both GCNRA and GCNP and continue to destabilize the historic properties found there. The degradation of historic properties due to natural causes remains the biggest challenge faced by historic property managers. Rain events cause gullying and remove the sediment that surrounds the historic properties along the Colorado River. Little can be done to slow these climatic processes although implementing management strategies to stabilize and minimize sediment losses may be effective tools in the future.

4.17.3.8 Tribal Resources

Actions contributing to cumulative impacts on Tribal resources include the continued use or reopening of breccia pipe uranium mines adjacent to the park, the development of new mines on state land lying within the Grand Canyon watershed, continued traffic of visitors to sites sacred to the Tribes, and specific projects, including the Lake Powell Pipeline, the Grand Canyon Escalade, and the Red Gap Ranch Pipeline.

Uranium prospecting and mining in the Grand Canyon watershed could contribute to cumulative effects on Tribes. Uranium mining has the potential to contaminate water sources that supply aquifer systems that feed springs, seeps, and their associated ecosystems within the Grand Canyon National Park (GCNP 2013). Many Tribes consider drilling or mining to be wounding the earth (BLM 2011). In 2012, the decision was made to withdraw over a million acres of federal lands surrounding GCNP in northern Arizona from uranium mining for the next 20 years. However, four existing mines were grandfathered and continue to operate intermittently as the price of uranium fluctuates. In addition, the withdrawal of federal lands has resulted in the concentration of new uranium exploration on state lands, some of which are within the Grand Canyon watershed. Past mining has resulted in the contamination of springs and seeps feeding the Grand Canyon, reducing their sacred nature. Uranium mining is currently taking place at sacred sites, including the Red Butte Traditional Cultural Property south of GCNP. Tribes in the region have expressed concern that contamination in the drainage to Havasu Canyon or in other watersheds and aquifers would be devastating to the downstream resources of importance to the Havasupai (Havasupai Tribal Council 2015). However, the LTEMP alternatives do not include any action that would result in water contamination and none are expected to contribute to cumulative impacts.

Continued use of the riparian zone by visitors to the Canyons has the potential to result in damage to places of cultural importance to the Tribes. Continued disturbance over time and space could result in the loss of the function and sacredness of traditional cultural places. These potential losses can be partially mitigated by the education of canyon visitors regarding the sanctity of the Canyons.

Actions affecting aquatic life, vegetation, and wildlife would also affect resources of value to Tribes (see Sections 4.5, 4.6, and 4.7). For example, changes in the tamarisk population due to the tamarisk leaf beetle and splendid tamarisk weevil, as well as long-term changes in the climate could contribute to cumulative impacts on riparian ecosystems across the Colorado River watershed. A summary of such impacts on Tribal resources is provided in Section 4.9.3.

The Lake Powell Pipeline proposes to carry water from Lake Powell to Sand Hollow Reservoir near St. George, Utah, to help meet water demand in southwestern Utah (UBWR 2011c). Impacts on historic properties have not been assessed for this project. Impacts on other resources of Tribal importance from the pipeline could include loss of some wildlife habitat and temporary loss of vegetation and riparian communities. The Red Gap Ranch Pipeline, which would withdraw and convey groundwater to augment Flagstaff's water supply, could affect springs of importance to Tribes, although the impacts of this action have not yet been assessed.

LTEMP alternatives that include mechanical trout removal or TMFs (all Alternatives except F), may have an adverse effect that would add to the cumulative impacts on Tribal resources (see also Table 4.9-2).

4.17.3.9 Recreation, Visitor Use, and Experience

Section 3.10 presents the recreational resources and activities that could be affected by the LTEMP alternatives. Most of the LTEMP alternatives would result in fewer navigation concerns, lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G). Section 4.10 presents the estimated incremental effects of the alternatives on those recreational resources and activities. The following paragraphs analyze the potential cumulative effects of past, present, and future actions on recreation resources that may also incur incremental effects from the LTEMP alternatives. Other resources analyzed separately that could incur cumulative effects that might also affect recreation include sediment, water quality, and the trout fishery below Glen Canyon Dam.

Some of the past and present actions described in Section 4.17.1.1, including natural events, could have effects on recreation. The past and present actions that could affect camping and beach access are those that affect sediment transport and deposition. Among these, the 2007 Interim Guidelines affect sediment retention and deposition through required equalization flows, which tend to erode beaches, while the 2011 HFE protocol would benefit beach and campsite building through sediment deposition. Such effects are already captured in the analysis of the LTEMP alternatives, which are subject to the provisions of ongoing programs.

Among ongoing actions that could affect recreation, visitor use, and experience, is the 2006 CRMP, which sets the number of annual launches for commercial and noncommercial boating and rafting.

The Comprehensive Fisheries Management Plan and the Non-native Fish Control Program would protect and benefit recreational fishing below Glen Canyon Dam. These two management programs would limit the effects of the LTEMP alternatives on the recreational fishery. Most of the alternatives incorporate management actions consistent with these plans, including TMFs and mechanical removal of trout. These plans and actions would tend to reduce cumulative impacts on the trout fishery through active management.

Of the reasonably foreseeable future actions, the proposed Grand Canyon Escalade project, including a gondola running from the canyon rim to the canyon floor near the confluence of the Little Colorado River and the Colorado River would contribute to cumulative impacts on recreational resources. The nature of effects, positive or negative, would depend on the perspective of a particular visitor. Users of the facility would benefit from the services offered. Adverse effects on wilderness experience are discussed in Section 4.17.10. Overall, however, effects of the Escalade project on recreationists are expected to be negative, because the vast majority of visitors come to experience natural beauty and solitude, which is incompatible with development within the Grand Canyon.

Climate change could affect recreation resources in a number of ways, some of which would add significantly to effects from ongoing actions and trends discussed. Warming temperatures could reduce runoff and water supply to the Colorado River and increase water demand from municipalities and for cooling, further reducing supply. Reduced availability of water could lower the elevation of Lake Powell, leading to warming and reduced flows below the Glen Canyon Dam. Warming could reduce DO levels in tailwaters. These factors could affect the health of the trout fishery below the dam and could affect boating through lower flows and higher daily fluctuations, as discussed in the previous paragraph. The combination of climate change and increasing water demands from regional population growth could increase the cumulative effects of reduced water availability.

The LTEMP alternatives would vary with respect to recreation, but would not significantly add to cumulative effects on recreation. Most alternatives would result in a reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G).

4.17.3.10 Wilderness

Wilderness character, as used in this EIS, is defined in Section 3.11 as the wilderness values and experience that may be impacted by LTEMP alternatives. Section 4.11 analyzes potential direct impacts on wilderness values and experience of the alternatives. In this section, potential cumulative effects on wilderness experience caused by other past, present, or future actions in the region are analyzed; aspects of the analysis of cumulative effects on recreation (Section 4.17.3.10) are also relevant to this discussion.

The GCNP Backcountry and Fire Management Plan would tend to benefit visitor use and experience under all the LTEMP alternatives through the protection of wilderness and visual resources and soundscapes, while mitigating to some extent visitor effects on the same resources.

The 2006 CRMP, which regulates commercial and noncommercial boating and rafting, would also tend to enhance visitor experience while protecting natural and cultural resources. By limiting the number of rafters on the river, this plan would protect wilderness experience and solitude. The 2010 Abandoned Mine Closure Plan could also enhance wilderness experience and protect natural resources through restoration of a more natural state. Similarly, the 2012 withdrawal of approximately a million acres of federal land in the vicinity of GCNP from entry for uranium mining would enhance wilderness values regionally by limiting industrial development in areas surrounding the parks.

With respect to foreseeable actions in the study area, the proposed Noise and Flight management alternatives could have a substantial beneficial effect on wilderness values in GCNP. The proposed Grand Canyon Escalade development on 420 acres near the confluence of the Little Colorado and Colorado Rivers could have adverse effects on wilderness values and experience in that area. Visitors seeking solitude or a wilderness experience could be adversely affected by the visual and noise effects and the presence of infrastructure, which is incompatible with the character of GCNP.

Basin-wide trends that could affect wilderness values and experience would be primarily those related to climate change. Wilderness and wilderness experience would be adversely affected to the extent that warming and reduced water availability promote the growth of invasive and nonnative species, which would alter the native character of vegetation. Low water availability could cause crowding and loss of solitude on the river due to reduced navigability and delays at rapids from periodic low flows.

The LTEMP alternatives vary with respect to their impact on wilderness experience. Disturbance from non-flow actions would occur under all alternatives; the most crowding at rapids would occur under Alternative E; alternatives with greater fluctuations (e.g., Alternatives A, B, and E) could affect wilderness character. None of the alternatives would significantly contribute to the cumulative impacts for this resource.

4.17.3.11 Visual Resources

The current condition of visual resources is described in Section 3.12; this reflects the effects of past and present cumulative impacts on resources within the project area. Section 4.12 discussed the potential impacts of the various LTEMP alternatives on visual resources within the project area. Visual resources within the shorelines and waters of the Colorado River between Glen Canyon Dam and Lake Mead, the shorelines of Lake Powell and Mead, and the general landscape of the area may also be affected by reasonably foreseeable actions and basin-wide factors contributing to cumulative impacts, including the Lake Powell Pipeline Project, uranium mining, the Grand Canyon Escalade development, water use, and climate change.

Increased water demands from population and industrial growth, coupled with conditions brought on by climate change such as severe drought and higher temperatures, could lead to lower Lake Powell reservoir levels. In addition, the Lake Powell Pipeline Project would likely result in slightly lower Lake Powell reservoir levels (UBWR 2011a,b). Additional impacts could result from the pipeline alignment, proposed facilities, and transmission lines associated with the Lake Powell Pipeline Project. No new infrastructure is proposed by any of the LTEMP alternatives; however, if water is transferred to Sand Hollow Reservoir from Lake Powell, the water level in Lake Powell could become lower, resulting in a slight increase in the height of the calcium-carbonate ring that surrounds Lake Powell and increasing the exposure of sediment deltas. These actions could also slightly increase the months of exposure of Cathedral-in-the-Desert.

Uranium mining operations have the potential to change the landscape character in the project area. The Grand Canyon Escalade development project includes a gondola, riverwalk, amphitheater, visitor center, and retail complex. The development would be visible from six of the seven eastern viewpoints in GCNP (Confluence Partners, LLC 2012b) and would cause a visual contrast with the surrounding natural environment of the Grand Canyon and Colorado

River. Impacts on the landscape under the proposed LTEMP action are negligible and are not expected to contribute to cumulative impacts affecting the landscape character.

4.17.3.12 Hydropower

Power operations and power marketing as they relate to Glen Canyon Dam and the Glen Canyon powerplant are described in Section 3.13; Section 4.13 presented the potential impacts that change in dam operations under the LTEMP alternatives would have on the economic value of hydropower resources and on electricity capacity expansion necessary for the eight largest WAPA customer utilities to replace lost hydropower generation, as well as the resulting impacts on retail electricity rates charged by the eight largest customer utilities. Increased demand for electricity in the service territories of the eight largest WAPA customer utilities and planned retirement of existing powerplant generating capacity would require an estimated 4,820 MW of new capacity to be built over the next 20 years (Section 4.13).

The incremental impact of the LTEMP alternatives generating capacity over the 20-year period would be relatively small (<1% of baseline) and variable. Changes in operations at Glen Canyon Dam (relative to current baseline conditions under Alternative A) would reduce available generating capacity at Glen Canyon Dam under all LTEMP alternatives except Alternative B. This reduction in capacity would be replaced by purchases from other sources or construction of new capacity.

The LTEMP alternatives vary with respect to hydropower production, hydropower capacity, and retail rates, and therefore cumulative impacts. Alternatives with higher fluctuation levels (Alternatives A, B, D, and E) achieve higher values of generation and capacity and lower impacts on retail rates than do alternatives with steadier flows (Alternatives C, F, and G), especially if more water is released in the high-demand months of July and August. Alternatives A and B would have the least effect on the value of generation, the value of capacity, and retail rates, while Alternatives F and G would have the highest.

Changes in operations under LTEMP alternatives could reduce available generating capacity, necessitating the purchase of replacement capacity from other sources and potentially increasing the wholesale power rates to entities allocated preference power. The average change in the retail rate (residential and commercial utility bills) varies from a decrease of 0.27% in Alternative B to an increase of 1.21% in Alternative F. The average change in the monthly residential electricity bill varies from a decrease of $0.27 in Alternative B to an increase of $1.02 in Alternative F.

Since the implementation of MLFF, between 1997 and 2005, multiple restrictions have been placed on the variability of water released from the dam, thus restricting dam operational flexibility. Under the current operating regime, described in more detail in Section 3.13.1.3, fluctuations in release rates, ramp rates, and maximum hourly increases/decreases are restricted and the maximum release rate for power generation is limited to 25,000 cfs. Maximum releases above 25,000 cfs occur through bypass tubes to achieve a constant release rate. Bypassing water around generators produces no energy, which can result in additional purchases of replacement power. The average annual costs associated with reductions in electricity generation over this time period have ranged from $38 million to $50 million (in 2009 dollars) (Veselka et al. 2010).

Changes in operations at the Flaming Gorge Dam and the Aspinall Unit are expected to result in a reduction of generating capacity 529,800 and 9,914 MWh (on an average annual basis), respectively (Reclamation 2005b, 2012i). These reductions in capacity will necessitate replacement by purchases from other sources or construction of new capacity over the 20-year period.

Changes at NGS to meet air emissions requirements may result in a reduction in generation output at the facility and its contribution to power in the Western Interconnection. This could result in excess transmission capacity within the Western Interconnection.

4.17.3.13 Socioeconomics and Environmental Justice

Actions and basin-wide trends contributing to cumulative impacts in the project area (including Lake Powell, Lake Mead, and the stretch of the Colorado River between them) are those that affect the economic valuation of its recreation resources and its recreational visitation and expenditure rates. Those actions and trends having a high, adverse, and disproportionate impact on minority and low-income populations are also of concern. The most significant trends affecting recreation are those related to climate change (decreased water supply and drought), because they have a direct effect on reservoir levels (exposed beaches and mudflats) and the seasonal timing of fluctuations in river flow. Regional economics (i.e., expenditures by visitors) for various types of recreational activities, including angling, rafting, and boating, as well as expenditures on gasoline (for vehicles and boats), camping fees or motel expenses, guide services, and fishing license fees are somewhat controlled by NPS regulations; the number of boating trips are controlled as specified in the CRMP and the Comprehensive Fisheries Management Plan cited in Table 4.17-1. These are not expected to change significantly under any of the LTEMP alternatives.

The impact analysis determined on the basis of the 2010 Census that minority or low-income populations exist in some block groups within San Juan (Utah) and Coconino (Arizona) counties (Section 4.14.2.4). Impacts on Tribes are associated with alternatives that incorporate frequent trout control actions (Alternatives C, D, and G), which affect Tribal values, or result in increased economic impacts on Tribes associated with the cost of electricity (especially Alternatives F and G).

4.17.3.14 Air Quality and Climate Change

The current condition of local and regional air quality is described in Section 3.15; Section 4.15 presented the potential impacts of the LTEMP alternatives on visibility within the project area (GCNP and the six-state area). Air quality is affected by air emissions from both natural (e.g., wildfires and windblown dust) and manmade (e.g., power generation from fossil fuel-fired plants) sources. The primary cause of visibility degradation in the region is the scattering and absorption of light by fine particles. Other important contributors to visibility degradation include combustion-related sources, fugitive dust sources, and particulate organic matter. Emissions of SO_2 and NO_x from fossil fuel combustion are the major manmade causes of visibility impairment; these emissions have been substantially reduced in the six-state area in the past decade in response to state and federal requirements (Section 3.15.2).

The construction of new powerplants (and the renewal of existing coal-fired plants permits) to meet energy demands from population and industrial growth in the region, coupled with drought conditions brought on by climate change that could increase the potential for wildfires and dust storms, could increase visibility impacts in the foreseeable future. The natural scattering of light would continue to be the main contributor to visibility impairment (haze) in the region, including GCNP. Other significant contributors to visibility degradation include wildfires, windblown dust, and emissions from metropolitan areas (automobiles, manufacturing, coal-fired powerplants, and combustion sources like diesel engines).

Although hydropower generation at Glen Canyon Dam does not generate air emissions, dam operations can affect ambient air quality by causing a loss of generation that is offset by generation from coal, natural gas, or oil units (Section 4.15.1). Under baseline operations (Alternative A), emissions of SO_2 and NO_x would be about 10% and 3.0% of the total emissions over the Western Interconnection region, respectively. Air quality impacts due to emissions under the other alternatives would be negligible because they would be only slightly increased or decreased relative to the baseline.

The EPA's Clean Power Plan Proposed Rule (currently stayed by the U.S. Supreme Court) would have a beneficial impact on the air quality in the region by mandating reductions in CO_2 emissions from fossil fuel-fired powerplants (to 30% below 2005 levels by 2030). The closure of three coal-burning units at the FCPP may also have a beneficial impact by reducing levels of NO_x and PM pollutants that may contribute to regional haze and visibility issues in the GCNP. The change to control technology or reduction of generation output at the NGS to meet air emissions requirements will also reduce levels of NO_x pollutants in the region.

The incremental impact of the LTEMP alternatives on air quality over the 20-year period is based on the emissions associated with power generation needed from other powerplants to meet uninterrupted power demand of customers in the region. There is negligible difference in the additional power generation needed among the alternatives (4,172 to 4,250 GWh per year); the differences in SO_2 and NO_x precursor emissions are also negligible (Table 4.15-1).

GHG emissions under all the LTEMP alternatives can be compared to total U.S. GHG emissions at 6,810.3 MMt CO_2e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions relative to total U.S. GHG emissions are less than 1%, and range from 0.8089% (Alternative A) to 0.8094% (Alternatives F and G). Therefore, potential impacts of dam operations on climate change under the various alternatives are expected to be very small.

4.18 UNAVOIDABLE ADVERSE IMPACTS

On the basis of the assessments presented in Sections 4.1–4.17, each of the alternatives is expected to result in some unavoidable adverse impacts on resources. These adverse impacts result from the flow and non-flow actions included in each alternative and could be minimized through adaptive management and implementation of mitigation measures.

All of the alternatives, including Alternative A, would result in continued reductions (for continued compliance with the Grand Canyon Protection Act) in hydropower production relative to pre-1996 ROD operations that more closely matched generation with electrical demand, due to restrictions on maximum and minimum flow, within-day fluctuation levels, and ramping rates. Steady flow alternatives (Alternatives F and G) would result in the greatest adverse impacts on hydropower value. Alternative B would result in an increase in hydropower energy and capacity compared to Alternative A; Alternatives D and E would produce less energy and capacity than Alternative A; Alternative C would produce less than Alternatives D and E, but more than Alternatives F and G. Alternative F would produce less energy and capacity than any of the alternatives.

Under all of the alternatives, sediment availability in the river channel below the dam would continue to be limited due to the presence of the dam. No operational alternative can reverse the reduction in sediment availability. Because of this sediment-depleted condition, all of the alternatives would continue to produce a net loss of sand from the Colorado River ecosystem. Alternatives C, D, E, F, and G retain more sandbars than Alternative A or Alternative B.

Implementation of mechanical removal of trout and TMFs would represent an unavoidable adverse impact on certain Tribes if these actions are needed to manage the trout fishery and mitigate trout impacts on humpback chub, because these actions are not in keeping with important Tribal values. The adverse impacts of mechanical removal could be mitigated with the provision of beneficial use (e.g., making euthanized fish available for human consumption). Any other mitigation to avoid adverse impacts would need to be identified in discussion with the Tribes.

The remaining unavoidable adverse impacts on certain resources are those associated not with the alternatives themselves; instead, they are consequences of existing operational rules (i.e., requirements of the Law of the River and the 2007 Interim Guidelines; Reclamation 2007a), 1996 Glen Canyon Dam ROD (Reclamation 1996), and the presence of Glen Canyon Dam and current dam infrastructure. For example, temperature and sediment impacts of all alternatives are related to the inability of operations themselves to provide for warmer temperatures or restore sediment supplies. Infrastructure changes, which are not within the scope of the LTEMP EIS, could mitigate those impacts; however, without that infrastructure, these adverse impacts are unavoidable.

4.19 RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM PRODUCTIVITY

Under all alternatives, different restrictions on flow fluctuations result in tradeoffs between peak hydropower production and productivity of the environment, which is largely related to increased nearshore habitat stability, aquatic food base productivity, and sandbar building downstream from the dam. For example, alternatives that have increased flow fluctuations or uneven monthly release volumes, such as Alternatives A and B, benefit peak hydropower energy and capacity and other resources (such as humpback chub) but result in less habitat stability and sandbar building. Alternatives with steady flows, such as Alternatives F and G, have the greatest reduction in peak hydropower energy and capacity, but result in more habitat stability and sandbar building downstream from the dam, and corresponding benefits for other resources such as recreation, aquatic food base, and trout. As a result, each of the alternatives presents a different balance between impacts on resources that appear to benefit from increased fluctuations and those that benefit from reduced fluctuations. Alternatives C, D, and E represent alternatives with more even monthly release volumes, and in the case of Alternatives C and D, fluctuation levels that are comparable to or lower than those under Alternative A. These alternatives were designed to strike a more even balance among resource impacts. However, regardless of the alternative, experimental flow and non-flow actions associated with alternatives (e.g., HFEs, TMFs, mechanical trout removal) would be tested in an attempt to maintain a balance that improves long-term productivity of the environment downstream of Glen Canyon Dam. Similarly, experimental elements of the alternatives are designed to improve our understanding of how resources respond to operations and how management actions can be best used to avoid, minimize, or mitigate impacts on resources and the long-term productivity of resources analyzed in the LTEMP EIS.

4.20 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Any experiment or operation that bypasses Glen Canyon Dam generators (e.g., HFEs that exceed powerplant capacity through generator bypass) would cause an irretrievable loss of hydropower production. Hydropower production forgone on a given day due to flows that reduce flexibility (e.g., lower summer flow or reduced fluctuations under certain alternatives) would create an irretrievable loss (see Section 4.13.2.1).

There could be some small differences among alternatives in total air emissions (<0.1% difference in emissions of SO_2, NO_X, or GHGs) that are related to differences among alternatives in the amount of energy and capacity that would be provided by Glen Canyon Dam. As part of an integrated electric grid, any loss of generation or capacity from Glen Canyon Dam must be offset by generation from a mix of other sources, including renewable energy sources and fossil-fuel-fired powerplants. The portion of the energy that comes from fossil-fuel-fired powerplants would produce these small differences in emissions; see sections 4.15 and 4.16.

Archeological sites by their nature are non-renewable, therefore any loss due to dam operations would be irretrievable. See Section 4.8.3 for the relative performance in comparison to Alternative A.

No other instances of irreversible or irretrievable commitments of resources are expected under any of the alternatives. Although operations, flow actions, non-flow actions, and experiments could result in unexpected impacts on natural and cultural resources, a long-term monitoring program implemented as part of the ongoing Glen Canyon Dam Adaptive Management Program would be used to inform the need for changes in operations and actions to minimize impacts and improve downstream resources in accordance with the objectives of this EIS. Safeguards have been incorporated into alternatives, including implementation considerations that would preclude taking specific actions if implementation would result in unacceptable adverse impacts, and off-ramps that would be used to alter operations or stop actions to prevent irreversible losses.

5 CONSULTATION AND COORDINATION

One intent of the National Environmental Policy Act of 1969, as amended (NEPA), is to encourage the participation of federal and state agencies and affected citizens in the assessment procedure, as appropriate. Consultation, coordination, and public involvement are integral to identifying relevant issues and concerns and ensuring that these issues are addressed. For this Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS), this was accomplished primarily through public meetings and workshops, informal and formal agency meetings, webinars, individual contacts, website updates, news releases, and *Federal Register* notices.

Acting as joint-lead agencies, the Bureau of Reclamation (Reclamation) and the National Park Service (NPS) have prepared this EIS in close coordination with several federal and state agencies (see Section 1.3). Development of this EIS also included input from Tribal governments, local agencies, programs, nongovernmental organizations, and the general public. This chapter summarizes the formal consultation and coordination that have occurred during the preparation of this EIS.

5.1 CONSULTATION AND COORDINATION WITH OTHER AGENCIES AND PROGRAMS

5.1.1 U.S. Department of the Interior

The U.S. Department of the Interior (DOI), through Reclamation and NPS, has prepared this EIS, with assistance from Argonne National Laboratory (Argonne) and the U.S. Geological Survey (including staff from the Patuxent Wildlife Research Center, Grand Canyon Monitoring and Research Center, and Southwest Biological Science Center). Reclamation has the primary responsibility for operating Glen Canyon Dam. NPS has the primary responsibility for managing downstream resources and visitors for the Grand Canyon National Park, Glen Canyon National Recreation Area, and Lake Mead National Recreation Area. As joint leads, both agencies have been equally involved in all aspects of the development of the LTEMP and EIS.

5.1.2 Cooperating Agencies

On December 8, 2011, in accordance with Title 40 *Code of Federal Regulations,* Part 1501.6 (40 CFR 1501.6) of the Council on Environmental Quality (CEQ) regulations for implementing NEPA and 43 CFR 46.225 of the DOI's regulations for implementing NEPA, Reclamation and NPS invited 25 federal, Tribal, state, and local government agencies to participate in the development of the EIS as Cooperating Agencies. Fifteen of these agencies expressed interest in participating as Cooperating Agencies. The Cooperating Agencies, which include three federal entities, five state agencies, and six Tribes, are listed in Table 5.1-1, along with descriptions of their participation.

All Cooperating Agencies have had the opportunity to participate in regular meetings and workshops and webinars related to the development of this EIS, participate in monthly meetings with the joint leads, and review and comment on the Draft EIS. Beginning in February 2012, the Cooperating Agencies met every month during the preparation of the EIS. In addition, more than 30 meetings, workshops, and webinars were conducted with stakeholders and Cooperating Agencies to assist in the development of alternatives and performance measures, conduct the Structured Decision Analysis (SDA), and provide general status updates. Federal Cooperating Agencies (i.e., Bureau of Indian Affairs [BIA], U.S. Fish and Wildlife Service [FWS], and Western Area Power Administration [WAPA]) also participated in the process of alternative development for the EIS.

5.1.3 American Indian Tribes

As part of the government's Treaty and Trust responsibilities, the Federal Government works on a government-to-government basis with American Indian Tribes. The government-to-government relationship and the process for developing open and transparent communication, effective collaboration, and informed federal decision-making with Indian Tribes was identified in Executive Order (E.O.) 13175, "Consultation and Coordination with Indian Tribal Governments" (U.S. President 2000); E.O. 13007, "Indian Sacred Sites" (U.S. President 1996); Secretarial Order (S.O.) 3206, "American Indian Tribal Rights, Federal-Tribal Trust Responsibilities, and the Endangered Species Act" (DOI 1997); S.O. 3317, "Department of the Interior Policy on Consultation with Indian Tribes" (DOI 2011a); and the President's "Memorandum on Government-to-Government Relations with Native American Tribal Governments" (U.S. President 1994a). In addition, Section 106 of the National Historic Preservation Act (NHPA) requires federal agencies to consult with Indian Tribes on undertakings on Tribal lands and on historic properties of significance to the Tribes that may be affected by an undertaking (36 CFR 800.2 (c)(2)). Both Reclamation and NPS coordinate and consult with all Tribal governments, Native American communities and organizations, and Tribal individuals whose interests might be directly and substantially affected by activities within their jurisdiction.

Government-to-government consultation was conducted throughout development of this EIS, in accordance with provisions of the Executive Orders and Secretarial Orders listed above as well as Section 106 of the NHPA, and any additional applicable natural and cultural resource laws (e.g., NEPA, the Endangered Species Act [ESA], NHPA, and Migratory Bird Treaty Act), as well as agency-specific guidance, such as:

- DOI, Departmental Manual, *Departmental Responsibilities for Indian Trust Resources*, 512 DM 2 (1995).

- DOI, Departmental Manual, *Departmental Responsibilities for Protecting/ Accommodating Access to Indian Sacred Sites*, 512 DM 3 (1998).

TABLE 5.1-1 Summary of Cooperating Agency Involvement

Cooperating Agency	Type	Summary of Involvement
Arizona Game and Fish Department (AZGFD)	State	AZGFD is a Cooperating Agency in recognition of its role in conserving, enhancing, and restoring Arizona's diverse wildlife resources and habitats. AZGFD is also a member of the Glen Canyon Dam Adaptive Management Work Group (AMWG). AZGFD participated in several stakeholder meetings, and representatives offered expertise during development of resource goals, performance metrics, and the aquatic modeling approach.
Bureau of Indian Affairs (BIA)	Federal	BIA is a Cooperating Agency in recognition of its administration of federal trust responsibility to Indian Tribes. BIA assisted in government-to-government consultations and served in an advisory capacity to Reclamation and the Indian Tribes.
Colorado River Board of California (CRBC)	State	CRBC is a Cooperating Agency in recognition of its responsibility for maintaining or increasing the quantity of California's Colorado River water resources. CRBC is also a member of the Glen Canyon Dam AMWG and represents California as part of the group of seven Basin States that have interests in the Colorado River. CRBC contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.
Colorado River Commission of Nevada (CRCN)	State	CRCN is a Cooperating Agency in recognition of its responsibility for acquiring and managing water and hydropower resources from the Colorado River. CRCN is also a member of the Glen Canyon Dam AMWG and represents Nevada as part of the group of seven Basin States that have interests in the Colorado River. CRCN contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.
The Havasupai Tribe	Tribe	The Havasupai Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. Havasupai representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and have contributed written portions to the EIS.
The Hopi Tribe	Tribe	The Hopi Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and Technical Working Group (TWG). Hopi representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the EIS.

TABLE 5.1-1 (Cont.)

Cooperating Agency	Type	Summary of Involvement
The Hualapai Tribe	Tribe	The Hualapai Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Hualapai representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the EIS.
The Kaibab Band of Paiute Indians	Tribe	The Kaibab Band of Paiute Indians is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Kaibab representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and provided comments on performance metrics and resource goals.
The Navajo Nation	Tribe	The Navajo Nation is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Navajo representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and provided comments on performance metrics and resource goals.
The Pueblo of Zuni	Tribe	The Pueblo of Zuni is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. Zuni representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the EIS.
Salt River Project (SRP)	Public Utility	SRP is a Cooperating Agency in recognition of its role as one of the primary public utility companies in Arizona. SRP participated in several Cooperating Agency and stakeholder meetings and provided comments on performance metrics and modeling results.
Upper Colorado River Commission (UCRC)	Inter-State	UCRC is a Cooperating Agency in recognition of its role as part of the group of seven Basin States that have interests in the Colorado River. UCRC is also a Glen Canyon Dam AMWG member. UCRC contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.

TABLE 5.1-1 (Cont.)

Cooperating Agency	Type	Summary of Involvement
U.S. Fish and Wildlife Service (FWS)	Federal	FWS is a Cooperating Agency in recognition of its jurisdiction by law and special expertise with respect to the ESA and biological resources within the study area. FWS has participated in the formation and development of LTEMP resource goals and objectives, performance metrics and alternatives, as well as the development of the aquatic modeling approach. In addition, a representative from FWS serves as the Tribal Liaison and has participated in government-to-government meetings with the Tribes.
Utah Associated Municipal Power Systems (UAMPS)	Public Utility	UAMPS is a Cooperating Agency in recognition of its role as a purchaser of electricity from the Colorado River Storage Project. UAMPS is also a member of the AMWG. UAMPS participated in Cooperating Agency and stakeholder meetings and provided comments on the performance metrics.
Western Area Power Administration (WAPA)	Federal	WAPA is a Cooperating Agency in recognition of its role in marketing and transmitting electricity from the Glen Canyon Dam. WAPA representatives participated in the development of alternatives and hydropower performance metrics and provided funds for the hydropower systems analysis.

- DOI, Order No. 3317, *Policy on Consultation with Indian Tribes*, December 1, 2011 (DOI 2011a).

- Reclamation, *Indian Policy of the Bureau of Reclamation*, 1998 (revised 2001).

- Reclamation, *Protocol Guidelines, Consulting with Indian Tribal Governments*, 2001 (Reclamation 2012g).

- *Programmatic Agreement among the Bureau of Reclamation, the Advisory Council on Historic Preservation, the National Park Service, the Arizona State Historic Preservation Officer, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Navajo Nation, San Juan Southern Paiute Tribe, Shivwits Paiute Tribe, and Zuni Pueblo Regarding the Operation of Glen Canyon Dam*, 1994 (Reclamation 1994).

- NPS, *Management Policies 2006* (NPS 2006d).

On November 30, 2011, 43 Tribes, bands, and organizations were formally invited to enter into government-to-government consultation on the LTEMP EIS. The letters, sent by the joint-lead agencies, provided notification of the intent to prepare the LTEMP EIS; initiated government-to-government consultation; and invited the Tribes to identify concerns related to historic properties, including traditional cultural properties and archaeological sites, natural resources, relevant Indian Trust assets, and other issues of importance.

A total of 31 Tribes responded to the invitation. Six Tribes agreed to participate as Cooperating Agencies (see Section 5.1.2); three Tribes (the Fort Mojave Tribal Council, Pueblo of Zia, and Gila River Indian Community) agreed to participate as Consulting Tribes; eight Tribes (Pueblo of Santa Clara, Ute Indian Tribe, Ute Mountain Ute, Pueblo of Nambe, Yavapai Apache, Paiute Indian Tribe of Utah, the Pueblo of Santa Ana, and the Fort Yuma Quechan) declined participation, but asked to remain on the mailing list; and 14 Tribes (Ak Chin Indian Community, Cocopah Indian Tribe, Fort McDowell Yavapai Tribal Council, Jicarilla Apache Nation, Ohkay Owingeh, Southern Ute Tribal Council, the Pueblo of Acoma, the Pueblo of Laguna, the Pueblo of Sandia, Yavapai-Prescott Indian Tribe, Chemehuevi Tribal Council, Tohono O'odham Nation, the Pueblo of Pojoaque, and the White Mountain Apache) declined participation in the LTEMP EIS. The joint leads have yet to receive a response to the request for consultation from the remaining 12 Tribes (Colorado River Indian Tribes, Las Vegas Tribe of Paiute Indians, Moapa Band of Paiute Indians, Salt River Pima-Maricopa Indian Community, San Carlos Apache Tribe, San Juan Southern Paiute Tribe, the Pascua Yaqui Tribe, the Pueblo of Cochiti, the Pueblo of Jemez, the Pueblo of San Felipe, the Pueblo of Tesuque, and Tonto Apache).

Cooperating and consulting Tribes were invited to attend meetings, workshops, and webinars, and to review various documents related to the development of the LTEMP EIS. A series of workshops, conference calls, and webinars were held with Tribes to identify Tribal resource goals and ways to measure the relative performance of alternatives against those goals. A list of major face-to-face meetings, webinars, and conference calls involving Tribes is provided in Appendix N, Table N-2. Meeting notes and other important documents related to the LTEMP EIS development process were sent to those Tribes who wished to remain on the mailing list. Reclamation and NPS will continue to provide consultation opportunities for interested Tribes and keep all Tribal entities informed about the NEPA process for the EIS. A full summary of Tribal communication as of March 2015 is provided in Appendix M.

5.1.4 Other Consultations

5.1.4.1 National Historic Preservation Act (NHPA)

Section 106 of the NHPA of 1966, as amended, and its implementing regulations, requires federal agencies to address the effect of projects on historical properties (i.e., resources determined eligible or listed on the *National Register of Historic Places* [NRHP]) and to give the State Historic Preservation Officers (SHPOs), Advisory Council on Historic Preservation (ACHP), and Traditionally Associated American Indian Tribes, as necessary, a reasonable opportunity to comment on such effects. Reclamation has the lead for Section 106 compliance and initiated the process of consultation with the Arizona SHPO. Consultations regarding eligibility of cultural resources to the NRHP and the effect of the proposed federal action are ongoing. In addition, consultations occurred with Tribal Historic Preservation Officers and Indian Tribes with concerns under E.O. 13007, "Indian Sacred Sites" (U.S. President 1996), the Native American Graves Protection and Repatriation Act, and Section 106 of the NHPA.

On November 30, 2011, 43 Tribes, bands, and organizations were formally invited to enter into government-to-government consultation on the LTEMP EIS (see Section 5.1.3). As part of the consultation process for this EIS, Reclamation will continue to identify concerns, assess the potential for cultural resources impacts, develop appropriate mitigation measures, and seek concurrence with the determination of effect. If adverse effects are identified, Reclamation would continue consultation to seek options to avoid, minimize, or mitigate the adverse effects on historic properties. Reclamation, in consultation with interested parties, is developing a Programmatic Agreement to address any cultural resource effects and mitigation measures. Reclamation and NPS conducted a number of formal and informal consultation meetings with Tribes (Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and the Pueblo of Zuni) just prior to and after the release of the DEIS.

5.1.4.2 State and Local Water and Power Agency Coordination

Reclamation and NPS have had various discussions with state and local water agencies regarding the proposed federal action. The seven Basin States in particular have been continuously engaged throughout the scoping and alternatives development processes. This engagement has consisted of conference calls, webinars, and face-to-face meetings to discuss process, resource goals, alternative characteristics, metrics to determine the relative performance of alternatives against those metrics, and the overall modeling approach used to quantify impacts.

One of the alternatives considered in the LTEMP EIS (Alternative E) was developed by the Basin States (as the Resource-Targeted Condition-Dependent Alternative) and submitted to the joint-lead agencies. The joint-lead agencies shared initial impact analysis results and insights that were ultimately used by the Basin States to further refine Alternative E.

The Colorado River Energy Distributors Association (CREDA) is an organization that represents consumer-owned electric systems that purchase federal hydropower and resources of the Colorado River Storage Project. While not a Cooperating Agency, CREDA, a member of the Glen Canyon Dam Adaptive Management Work Group (AMWG), submitted Alternative B, and Reclamation and NPS worked closely with CREDA to define and model resource effects of this alternative. CREDA has also participated in stakeholder meetings and provided comments on the performance metrics.

5.1.4.3 U.S. Fish and Wildlife Service (FWS)

FWS participated in the formation and development of LTEMP alternatives, providing expertise in several workshops and webinars. FWS also worked with the joint-lead agencies and subject matter expert groups in the development of resource goals and objectives and performance metrics to evaluate the alternatives. FWS provided expertise during the development of the aquatic modeling approach used in this EIS.

Reclamation and NPS consulted with FWS on the effects of the LTEMP on species listed under Section 7 of the ESA (The Biological Assessment is included in Appendix O of this EIS). This consultation was a continuation of ongoing consultation that has occurred since 1995. Reclamation has consulted with FWS on a total of five experimental actions. The Biological Opinion prepared for the LTEMP supersedes the 2011 opinion on the high-flow experimental protocol and nonnative fish protocols.

5.2 PUBLIC INVOLVEMENT

Public involvement in the NEPA process is intended to give the public the chance to provide input throughout the development of an EIS and the decision-making process for actions with environmental effects. An objective of public involvement is to obtain information from the public to assist the decision-maker (Secretary of the Interior) throughout the entire process, culminating in a Record of Decision and eventual implementation of the selected alternative. The primary goals of public involvement are:

1. *Credibility and transparency*: creating an open and visible decision-making process for groups with divergent viewpoints.

2. *Identifying public concerns and values*: providing a mechanism by which the involved agencies can understand the problems, issues, and possible solutions from the perspectives of the public.

3. *Developing a consensus*: providing a process for reaching a consensus on specific actions.

In order to identify issues, address public concerns, obtain public input, and keep the public informed, several opportunities were provided for public participation during the preparation of this EIS. These included an early and open public scoping process and public meetings related to development of preliminary alternatives. The public scoping process is described below in Section 5.2.1.

5.2.1 Public Scoping Process and Comments Received

The process of soliciting input from the public is called scoping. Public scoping is a phase of the NEPA analysis process and was intended to give the public the chance to comment on the LTEMP, recommend alternatives, and identify and prioritize the resources and issues to be considered in the EIS analyses. Consistent with CEQ requirements (40 CFR 1501.7) and DOI NEPA regulations at 43 CFR Part 46, an early and open public scoping process was carried out to determine the resources or issues to be evaluated in the LTEMP EIS, the alternatives to be included in the LTEMP EIS, and concerns or observations regarding Glen Canyon Dam operations and downstream resources. Reclamation and NPS have considered the public scoping comments in developing this EIS.

Reclamation and NPS published a Notice of Intent (NOI) to prepare the LTEMP EIS in the *Federal Register* (Volume 76, page 39435) on July 6, 2011 (DOI 2011b). The NOI provided initial information on the purpose and need of the LTEMP EIS, explained the decision for Reclamation and NPS to co-lead the project, and encouraged the participation of stakeholders in the development of the LTEMP EIS. The public scoping period started with the publication of the NOI and ended on January 31, 2012.

Early in the scoping process, Reclamation and NPS established a website for the LTEMP EIS (http://ltempeis.anl.gov) that provided background information about the project, information on public involvement, answers to frequently asked questions, and links to documents for review. During the public scoping process, a link to the project's online comment form was provided and made available on the NPS's Planning, Environment, and Comment website. In addition, project updates and announcements were made available via an email subscription list, press releases, and social media (e.g., Twitter and Facebook).

"A Notice to Solicit Comments and Hold Public Scoping Meetings on the Adoption of a Long-Term Experimental and Management Plan for the Operation of Glen Canyon Dam" was published in the *Federal Register* (Volume 76, page 64104) on October 17, 2011 (DOI 2011c), which provided the date, time, and place for six public meetings to be held to solicit public input on the scope of the EIS, including potential alternatives and issues to be addressed within the document. Meetings were held in the following locations:

- Phoenix, Arizona (November 7, 2011)
- Flagstaff, Arizona (November 8, 2011)
- Page, Arizona (November 9, 2011)
- Salt Lake City, Utah (November 15, 2011)
- Las Vegas, Nevada (November 16, 2011)
- Lakewood, Colorado (November 17, 2011)

The notice also indicated that there would be one web-based public meeting (November 15, 2011) for those who could not attend in person. The public was also notified of the meetings via a press release, local media outlets, and an op-ed article disseminated for publication in local and regional newspapers.

At the public meetings, the public could view exhibits about the project, discuss issues informally, and ask questions of technical experts and managers. A total of 221 people attended these meetings. For the web-based meeting, the public was able to listen to, via the Internet, a live overview presentation of the LTEMP EIS and to ask questions of technical experts and managers.

A total of 447 individuals, recreational groups, environmental groups, power customers or organizations, federal and state government agencies, and other organizations provided scoping comments on the LTEMP EIS. Although no formal campaign letters were received, some commenters chose to incorporate in their submissions entire letters or portions of letters from various other commenting organizations.

Comments received during the public scoping period covered a wide range of topics and issues and represented a variety of views and interpretations. Comments addressed various aspects of the proposed action, including the purpose and need (as stated in the July 6, 2011, NOI [DOI 2011b]); environmental issues; dam operations and hydropower; geographic and temporal scope; policy and regulatory concerns; LTEMP approach and considerations; alternatives; other issues; and stakeholder involvement. A detailed summary of comments received can be found in *Summary of Public Scoping Comments on the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement* (Argonne 2012), available on the LTEMP website (http://ltempeis.anl.gov).

In general, the most frequent topic for comments on the LTEMP EIS was related to environmental issues. Comments and concerns frequently raised by the public included restoration of the downstream Colorado River ecosystem; reestablishment of ecosystem patterns and processes to their pre-dam range of natural variability; elimination or minimization of further beach erosion; facilitation of sediment redeposition; in situ maintenance and preservation of the integrity of cultural and archeological resources; elimination of adverse impacts on and assistance in the recovery of native species; nonnative fish management; and assistance in repropagation of native riparian plant communities.

5.2.2 Public Meetings on Alternatives

Members of the public were invited to participate in a 2-day open public meeting on preliminary alternative concepts, hosted by Reclamation and NPS. The meeting was held on April 4 and 5, 2012, at the High Country Conference Center in Flagstaff, Arizona. More than 70 people attended the meeting, including members of the public, stakeholders, and project staff from Reclamation, NPS, and Argonne.

During this meeting, alternatives being considered for inclusion in the LTEMP EIS were presented and discussed. Stakeholders and other attendees who had alternatives to propose were able to present those ideas at the meeting; four individuals representing different stakeholder groups presented their ideas. Following the presentations, meeting attendees broke into smaller groups and focused on evaluating and refining the preliminary alternative concepts. These small groups reported their discussions in an open forum during the meeting.

Reclamation and NPS evaluated the feedback received at this meeting and used it to develop the final set of alternatives considered in this EIS (discussed in detail in Chapter 2). Maintaining that all alternatives meet the purpose and need of the proposed action, this evaluation resulted in new alternative concepts, the modification of existing concepts, and the combination of some concepts into single alternatives.

Regular updates of the LTEMP EIS process were provided at public meetings of the Glen Canyon Dam AMWG. LTEMP EIS joint leads regularly presented the status of preliminary EIS-related materials (e.g., purpose and need, resource goals, and preliminary draft alternatives) and coordination activities with the Cooperating Agencies. These meetings are described in more detail in Section 5.2.3.

5.2.3 Glen Canyon Dam Adaptive Management Working Group

The Glen Canyon Dam AMWG is a federal advisory committee. As an advisory committee, the AMWG has provided a forum for discussion of key issues related to the operation of Glen Canyon Dam among the federal agencies, Indian Tribes, environmental groups, recreational interest groups, federal power purchase contractors, and other stakeholders who have interests in the resources of the Colorado River. AMWG members meet several times throughout the year to discuss competing issues on how to protect downstream resources and strike a wise balance on river operations. Their recommendations are regularly provided to the Secretary by the Secretary’s Designee, who often brings these competing issues to a consensus (Reclamation 2014d).

Separate meetings regarding the LTEMP EIS have been held with the Glen Canyon AMWG because of its status as a Federal Advisory Committee. These meetings occurred on February 18–22, 2013, May 8, 2013, August 8–9, 2013, February 18–20, 2014, May 27, 2014, August 27–28, 2014, February 25–26, 2015, and May 28, 2015. These meetings were conducted to provide an explanation of alternatives, performance criteria, and SDA; conduct swing-weighting exercises; answer budget questions; and provide general status updates.

5.2.4 Public Involvement on the LTEMP DEIS

On January 8, 2016, the LTEMP DEIS was filed with Region 9 of the U.S. Environmental Protection Agency (EPA); a Notice of Availability and Notice of Public Meetings were published in the *Federal Register* (81 FR 963); and an email notification of the availability of the DEIS for download from the project website (www.ltempeis.gov) was sent to approximately 600 members of the public who had signed up for notification during the scoping period. Prior to this date, the DEIS was sent to each of the Governors, Senators, and Representatives from relevant congressional districts of the seven Colorado River Basin States (Arizona, California, Colorado, Utah, Nevada, New Mexico, and Wyoming).

In addition to making the DEIS available on the public website, 84 compact disc copies of the DEIS were mailed to individuals at their request; 46 copies were picked up at public meetings held for the DEIS; and copies were made available for public review after the DEIS was published at the following locations:

- J. Willard Marriott Library, University of Utah, 295 South 1500 East, Salt Lake City, Utah 84112.

- Cline Library, Northern Arizona University, 1001 S. Knoles Drive, Flagstaff, Arizona 86011-6022.
- Burton Barr Central Library, 1221 North Central Avenue, Phoenix, Arizona 85004.
- Page Public Library, 479 South Lake Powell Boulevard, Page, Arizona 86040.
- Grand County Library, Moab Branch, 257 East Center Street, Moab, Utah 84532.
- Sunrise Library, 5400 East Harris Avenue, Las Vegas, Nevada 89110.
- Denver Public Library, 10 West 14th Avenue Parkway, Denver, Colorado 80204.
- Natural Resources Library, U.S. Department of the Interior, 1849 C Street NW, Main Interior Building, Washington, D.C. 20240-0001.

The original 90-day public comment period was extended an additional 32 days (122-day total) to May 9, 2016, after several requests were received from the public and Cooperating Agencies. During the comment period, two in-person meetings and two Internet-based webinars were held to provide the public with information about the content and findings of the DEIS and to receive written comments on the DEIS. The meetings and webinars were held on the following dates:

- Webinar—Tuesday, February 16, 2016, at 6:30 p.m. Mountain Standard Time (MST);
- Meeting—Monday, February 22, 2016, at 6:00 p.m. MST, Flagstaff, Arizona;
- Meeting—Thursday, February 25, 2016, at 6:00 p.m. MST, Phoenix, Arizona; and
- Webinar—Tuesday, March 1, 2016, at 1:00 p.m. MST.

At these meetings, LTEMP staff were available to take comments and answer questions before and after presentations were made on the DEIS.

During the public comment period, the public was encouraged to submit comments electronically through the NPS Public, Environment, and Public Comment (PEPC) website. Comments were also received, however, through the mail or using a public comment form provided at the public meetings. More than 3,000 individual comment documents were received on the DEIS. Substantive comments within these documents were used to make changes to the DEIS when deemed appropriate and justified. Responses to comments are provided in Appendix Q of the EIS.

In addition to the public meetings described above, meetings were held with Cooperating Agencies, Tribes, and AMWG stakeholders after the comment review period ended to discuss potential revisions to the EIS.

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7 LIST OF PREPARERS

This chapter presents information on the preparers of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS). The list of preparers is organized by agency or organization, and information is provided on education, experience, and contribution to the LTEMP EIS.

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Rick Clayton	B.S., Civil Engineering; B.S., Environmental Economics; 14 years experience in reservoir operations; 3 years experience in powerplant operations. Upper Colorado Region General Engineer.	Reclamation lead for power resource analysis; hydrology and reservoir modeling
Todd Gaston	M.S. Resource Economics; B.S. Environmental Science; 7 years experience in natural resources management and economics. Technical Service Center, Economics and Resource Planning Team.	Technical analyst and subject matter expert, socioeconomics, recreational economics
Katrina Grantz	Ph.D., Civil Engineering; 14 years experience in water resources research, hydrology, and decision support systems; 8 years experience in reservoir operations. Upper Colorado Region/Hydraulic Engineer.	Co-lead EIS project manager. Lead author of Section 4.2 (water resources) and Appendix D, technical lead for reservoir operations and hydrology; reservoir modeling
Dave Harpman	Ph.D., Natural Resource Economics; MSc., Agricultural Economics; BSc., Fisheries Management; 24 years experience. Technical Service Center Natural Resource Economist.	Technical lead for recreational economics; subject matter expert, socioeconomics
Beverley Heffernan	B.A., History; 30 years experience in NEPA compliance. Upper Colorado Region/Manager, Environmental Resources Division.	Project management and review

Name	Education/Experience	Contribution
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Jim Prairie	Ph.D., Civil Engineering; 15 years experience in water resources research, hydrology, and salinity modeling, and decision support systems. Upper Colorado Region/Hydrologic Engineer.	Technical analyst and subject matter expert, reservoir operations and hydrology, climate change; reservoir modeling, water quality modeling
Kendra Russell	M.S., Geography and Environmental Engineering; B.S. Civil and Environmental Engineering; 6 years experience in water resources engineering. Technical Service Center, Sedimentation and River Hydraulics; Hydraulic Engineer.	Project management and review; subject matter expert, sediment resources and modeling
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Nick Williams	B.S., Civil and Environmental Engineering; M.S., Civil and Environmental Engineering; 5 years as an environmental engineer; 5 years as a water quality specialist. Upper Colorado Region/Water Quality Specialist.	Technical analyst and lead for temperature and water quality modeling
National Park Service		
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Name	Education/Experience	Contribution
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Jennifer Rebenack	M.S., Fisheries Biology; 8 years experience in fisheries and wildlife ecology and environmental compliance. Intermountain Region Colorado River Program Biologist.	Project management assistant
Argonne National Laboratory		
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Timothy Allison	M.S., Mineral and Energy Resource Economics; M.A., Geography; 24 years experience in regional analysis and economic impact analysis.	Lead author of hydropower and socioeconomics sections (Sections 3.13, 3.14, 4.14; Appendix L); technical analyst and lead for socioeconomic and environmental justice
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Edward Bodmer	M.B.A., Econometrics; B.S., Finance; 30 years experience in utility ratemaking and financial analysis.	Contributing author of retail rate sections (Section 4.13, Appendix K.3); technical lead for retail rate impact analysis

Name	Education/Experience	Contribution
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Vic Comello	M.S., Physics; 38 years writing and editing experience.	Contributing editor
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Jessica Griffin	M.S., Historical Archaeology; 3 years experience in cultural resources assessments.	Project management assistant
John Hayse	Ph.D., Zoology; 27 years experience in ecological research and environmental assessment.	Lead author of aquatic resource sections (Sections 3.5, 4.5; Appendix F); technical lead for aquatic ecology; lead technical analyst temperature suitability modeling
Ihor Hlohowskyj	Ph.D., Zoology; 37 years experience in ecological research; 35 years in environmental assessment.	Lead author of natural processes sections (Sections 3.4, 4.4); contributing author of aquatic resource sections (Sections 3.5, 4.5; Appendix F); technical lead for natural processes subject matter expert, native and nonnative fish
Pat Hollopeter	B.A., Religion; M.A., Philosophy; 30 years experience editing technical communication products.	Contributing editor
Mark Jusko	M.S., Computer Science; 34 years experience in software engineering.	Hydropower and power systems modeling and graphics
Kirk E. LaGory	Ph.D., Zoology; M.S., Environmental Science; 38 years experience in ecological research; 28 years in environmental assessment.	Argonne EIS project manager; lead author of introduction and alternatives sections (Chapters 1 and 2) and Appendices A and B; contributing author of water resources and wildlife sections (Sections 4.2, 4.7)

Name	Education/Experience	Contribution
James E. May	M.S., Water Resources Management; B.A., Zoology; 32 years experience in natural resources management; 11 years of consulting experience in land use planning and NEPA compliance.	Contributing author of recreation sections (Sections 3.10, 4.10); subject matter expert recreation, visitor use and experience
Michele Nelson	Graphic designer; 36 years experience in graphic design and technical illustration.	Graphics
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Terri Patton	M.S., Geology; 26 years experience in environmental research and assessment.	Lead author of cumulative impacts section (Section 4.17); subject matter expert geology, soil, sediment resources, and cumulative impacts
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Carolyn M. Steele	B.A., English; B.A., Rhetoric; 9 years experience in technical writing and editing.	Lead editor
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Name	Education/Experience	Contribution
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Tom Veselka	M.S., Meteorology; 34 years experience in energy, power, and environmental systems modeling/optimization.	Contributing author of hydropower sections (Section 4.13; Appendix K.1); subject matter expert, hydropower modeling and power systems analysis
William S. Vinikour	M.S., Biology with environmental emphasis; 38 years experience in ecological research and environmental assessment.	Lead author food base (Sections 3.5, 4.5; Appendix F) and wildlife sections (Sections 3.7, 4.7); subject matter expert, aquatic food base and wildlife
Cory Weber	M.S., Operations Management and Information Systems; 9 years experience in research software and visualization development.	Technical analyst hydropower modeling
Kelsey Wuthrich	B.S., Civil and Environmental Engineering; 2 years experience in environmental science.	Technical analyst sediment, cultural, recreation, and water use modeling
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U.S. Geological Survey		
Barbara Ralston	Ph.D., Botany; 28 years experience in floristics and 20 years experience in southwestern riparian ecology.	Lead technical analyst vegetation modeling
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Charles Yackulic	Ph.D., Ecology and Evolution; Research Statistician.	Lead technical analyst humpback-chub trout modeling; subject matter expert, aquatic ecology, aquatic modeling

Name	Education/Experience	Contribution
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Sarah Rinkevich	Ecological Services/Federal Tribal Liaison.	Federal Tribal Liaison
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Thomas Hackett	B.S., Management/Computer Information Systems; 9 years experience in electricity rates and budget analyses.	Contributing author of electrical wholesale rate section (Appendix K.2); technical analyst hydropower modeling and power systems analysis

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8 GLOSSARY

A

Abiotic: Absence of living organisms, includes chemical and physical environments and processes.

Aboriginal: The first or earliest known of its kind present in a region.

Above mean sea level (AMSL): Elevation or altitude of any object relative to the average sea level.

Acre-foot: Volume of water, 43,560 cubic feet (ft^3) (1,233 cubic meters [m^3], 325,851 gallons), that would cover 1 acre to a depth of 1 foot.

Active capacity: Reservoir capacity normally available to store and regulate reservoir inflows to meet established reservoir operating requirements. For Lake Powell, this reservoir storage capacity is nearly 21 million acre-feet (maf).

Active conservation capacity: Reservoir capacity assigned to regulate reservoir inflow for irrigation, power generation, municipal and industrial use, fish and wildlife, navigation, recreation water quality, and other purposes. Also referred to as active storage. For Lake Powell, this is the reservoir storage above the penstock openings at an elevation of 3,490 feet (ft) (1,064 meters [m]).

Active storage: See *active conservation capacity*.

Adaptive management: Method or system for examining alternative strategies for meeting measurable goals and objectives and then, if necessary and in response to new information and/or changing circumstances, adjusting actions according to what is learned.

Adaptive Management Work Group (AMWG): Federal advisory committee to the Secretary of the Interior. Incorporates those stakeholders with interest in the operation of Glen Canyon Dam and downstream resources and continues public involvement in the decision-making process.

Advection: The typically horizontal movement of a mass of fluid, such as water.

Adverse impact: Abnormal, harmful, or undesirable effect that results from taking a particular action.

Aeolian processes: Erosion, transport, and deposition of sediment by the wind. Commonly occurs in areas with sparse or nonexistent vegetation, a supply of fine sediment, and strong winds.

Aerate: To supply or impregnate with gas, usually air.

Affected environment: Existing biological, physical, social, and economic conditions of an area subject to change, both directly and indirectly, as the result of a proposed human action. Also, the chapter in an environmental impact statement (EIS) describing current environmental conditions. A description of the affected environment must include information necessary to assess or understand impacts, must contain enough detail to support the impact analyses, and must highlight environmentally sensitive resources.

Aggradation: Process of filling and raising the level of a streambed, floodplain, or sandbar by deposition of sediment. The opposite of degradation.

Aggregation: A consistent and disjunct group of fish that has no significant exchange of individuals with other aggregations, as indicated by recapture of tagged juveniles and adults and movement of radio-tagged adults.

Air quality: Measure of the condition, including health-related and visual characteristics, of the air. Often derived from quantitative measurements of the concentrations of specific injurious or contaminating substances (i.e., air pollutants).

Air Quality Control Region (AQCR): An interstate or intrastate area designated by the U.S. Environmental Protection Agency for the attainment and maintenance of National Ambient Air Quality Standards.

Albedo (effects): The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo; the albedo of soils ranges from high to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's albedo varies mainly through varying cloudiness, snow, ice, leaf area, and land-cover changes.

Algae: Simple plants containing chlorophyll; most live submerged in water.

Algal bloom: Rapid and flourishing growth of algae.

Allocation, allotment: Refers to a distribution of water through which specific persons or legal entities are assigned individual rights to consume pro-rata shares of a specific quantity of water under legal entitlements. For example, a specific quantity of Colorado River water is distributed for use within each Lower Division state through an apportionment. Water available for consumptive use in that state is further distributed among water users in that state through the allocation. An allocation does not establish an entitlement; the entitlement is normally established by a written contract with the U.S. government.

Alluvial: Formed by the action of running water, such as that related to river and stream deposits.

Alluvium: Sedimentary material (e.g., clay, silt, sand, gravel, or other particulates) transported and deposited by the action of flowing water.

Alternatives: Courses of action that may meet the specific goals and objectives of a proposed action, often by different means and at varying levels of accomplishment, including the most likely future conditions without the project (i.e., no action).

Ambient: Surrounding environment or natural conditions in a given place and time.

American Indian: The indigenous peoples in North America within the boundaries of the present-day continental United States, Alaska, and the island state of Hawaii.

American Indian Tribe: Any extant or historical clan, Tribe, band, nation, or other group or community of indigenous peoples in the United States.

American Indian Religious Freedom Act (P.L. 95-341) (AIRFA): Act requiring federal agencies to consult with Tribal officials to ensure protection of religious cultural rights and practices.

Amphibian: Cold-blooded, smooth-skinned vertebrate animal that has a life stage in water (e.g., hatches as an aquatic larva with gills) and a life stage on land (e.g., transforms into an adult with air-breathing lungs). Includes salamanders, frogs, and toads.

Amphipod: An order of crustacean that is found in almost all aquatic environments.

AMSL: See *above mean sea level*.

AMWG: See *Adaptive Management Work Group*.

Anaerobic bacteria: Bacteria that survive and grow in environments with little or no oxygen.

Ancillary services: Those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system. See *regulation* and *spinning reserves*.

Anions: Ions that carry a negative charge (e.g., chloride, nitrate, sulfate, and phosphate).

Anoxic: Areas of water that are depleted of dissolved oxygen.

Antecedent: Prior or preceding event, condition, or cause.

Anthropogenic: Created, caused, or produced by humans.

Apportionment: Refers to the distribution of Colorado River water available to each Lower Division state in normal, surplus, or shortage condition years, as set forth, respectively, in Articles II(B)(1), II(B)(2), and II(B)(3) of the 1964 Supreme Court Decree in the case of Arizona v. California.

Appropriation: Amount of water legally set apart or assigned to a particular purpose or use.

Aquatic: Living or growing in or on the water.

Aquatic biota: Collective term describing the organisms living in or depending on the aquatic environment.

Aquatic habitat: Bodies of water that provide food, cover, and other elements critical to the completion of an organism's life cycle (e.g., streams, rivers, and lakes).

Aquifer: Permeable water-bearing underground rock formation that readily yields usable amounts of water to a well or spring. The formation could be sand, gravel, limestone, and/or sandstone.

Archaeological and Historic Preservation Act (AHPA): Legislation that amended the Reservoir Salvage Act of 1960, requiring federal agencies to provide for the preservation of historical and archeological data that might otherwise be lost or destroyed as the result of any federally licensed activity or program causing an alteration of terrain.

Archaeological resource: Any material remains or physical evidence of past human life or activities that are of archeological interest, including the record of the effects of human activities on the environment. An archeological resource is capable of revealing scientific or humanistic information through archeological research.

Archaeological Resources Protection Act of 1979 (ARPA): Legislation establishing requirements to protect archaeological resources and sites on public lands and Indian lands and to foster increased cooperation and exchange of information between governmental authorities, the professional archaeological community, and private individuals.

Archaeological site: A place (or group of physical sites) in which evidence of past activity is preserved (either prehistoric, historic, or contemporary); that has been, or may be, investigated using the discipline of archaeology; and that represents a part of the archaeological record.

Archaic: In American archeology, a cultural stage following the earliest known human occupation in the Americas (about 5500 BC to AD 100). This stage was characterized by a hunting and gathering lifestyle and seasonal movement to take advantage of a variety of resources.

Archaeology: Study of human cultures through the recovery and analysis of their material remains.

Arid: A region that receives too little water to support agriculture without irrigation. Less than 10 in. of rainfall a year in a region is typically considered arid.

Arroyo: Gully or channel cut by an ephemeral stream.

Arthropod: Any of the invertebrate animals (such as insects, spiders, or crustaceans) having an exoskeleton, a segmented body, and jointed limbs.

Artifact: Object produced or shaped by human beings and of archaeological or historical interest.

Aspect: The direction in which a feature faces.

Assemblage: A collection or community of plants or animals characteristically associated with a particular environment, which can be used as an indicator of that environment.

Attainment Area: An area considered to have air quality as good as or better than the National Ambient Air Quality Standards for a given pollutant. An area may be in attainment for one pollutant and in nonattainment for others.

Attenuation: Gradual loss of strength or intensity.

Authorization: Act by the Congress of the United States that sanctions the use of public funds to carry out a prescribed action.

Automatic generation control (AGC): Computerized power system regulation to maintain scheduled generation within a prescribed area in response to changes in transmission system operational characteristics.

Available hydropower (AHP): The monthly capacity and energy that is actually available based on prevailing water release conditions.

Average peak annual discharge: Found by generating a list of the single highest value of discharge from each year and calculating the mean.

B

Backwater: A relatively small, generally shallow area of a river with little or no current. See *return-current channel*.

Bald and Golden Eagle Protection Act: Law passed in 1940 that prohibits anyone without a permit issued by the Secretary of the Interior from taking bald or golden eagles, including their parts, nests, or eggs.

Bank storage: Water absorbed and stored in the banks of a stream, lake, or reservoir, and returned in whole or in part as the level of the water body surface falls.

Base flow: Portion of stream or river discharge that is derived from a natural storage source (i.e., groundwater recharge).

Baseline: Information identified or found at the beginning of a study or experiment that serves as a basis against which subsequent findings are measured or compared.

Baseload: Minimum load in a power system over a given period of time.

Baseload plant: Energy plant or powerplant normally operated to produce the minimum amount of power required to meet some or all of a given region's continuous energy demands. Consequently, it operates essentially at a constant load.

Basin: Area of land that drains to a particular stream, river, pond, or lake.

Basin States: In accordance with the Colorado River Compact of 1922, the Colorado River Basin is comprised of those parts of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming within and from which waters drain naturally into the Colorado River. These seven states are referred to as the Basin States. See *Colorado River Compact of 1922*.

Bathymetric: Pertains to the study of the underwater depth of a lake, ocean, or reservoir floor.

Beach: Sandbar that generally is considered to have recreational value. See *sandbar*.

Bed elevation: Height of streambed above a specified level. Change in bed elevation in pools of the Colorado River commonly is used as a measure of change in the amount of sediment stored on the riverbed.

Bedload: Sediment moving on or near the streambed and frequently in contact with it.

Bed material: Unconsolidated material of which a streambed is composed.

Bedrock: Native consolidated, solid rock foundation underlying the surface. Above it is usually an area of loose, broken, and weathered unconsolidated deposits of soil, sand, clay, or gravel.

Benthic: Living in or occurring at the bottom of a body of water.

Biodiversity: Number and kinds of organisms per unit area or volume; the composition of species in a given area at a given time.

Biological Assessment: Document prepared for the Endangered Species Act of 1973 (ESA) Section 7 process to determine whether a proposed major construction activity under the authority of a federal action agency is likely to adversely affect listed species, proposed species, or designated critical habitat.

Biological control: The use of living organisms, such as predators, parasitoids, and pathogens, to control pest insects, weeds, or diseases. Typically involves some human activity.

Biological Opinion (BO): Document stating opinion of the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) as to whether a federal action is likely to jeopardize the continued existence of a threatened or endangered species or result in the destruction or adverse modification of critical habitat.

Biological response: Reactions or changes in cells, tissues, organs, and/or entire organisms resulting from chemical, physical, or environmental agents and stressors.

Biomass: Total amount of combustible solid, liquid, or gas derived from biological processes (e.g., living organisms) in a particular area or environment.

Biota: Living organisms (e.g., plants and animals) in a given region.

Blue-ribbon fishery: Designation made by the U.S. government and other authorities to identify recreational fisheries of extremely high quality. The designation is typically based on water quality, quantity, and accessibility; natural reproduction capacity; angling pressure; and the specific species present.

Bryophytes: Group of non-vascular, seedless plants including mosses, liverworts, and hornworts.

Bypass tube: Conduits that are used to release water in addition to the releases made through the powerplant. See *jet tube*.

C

Campable area: Areas suitable for recreational camping.

Candidate species: Plant or animal species about which sufficient information on biological status and threats is known to propose them as endangered or threatened. Undergoing status review by the FWS, but not yet officially listed as threatened or endangered under the ESA.

Capacity: In power terminology, the load for which a generator, transmission line, or system is rated; expressed in kilowatts. In this document, also refers to powerplant generation capability under specific operating conditions and the amount of marketable resource under such conditions.

Carbon dioxide (CO_2): A colorless, odorless, nonpoisonous gas that is a normal part of the Earth's atmosphere. Carbon dioxide is a product of fossil fuel combustion, but is also exhaled by humans and animals and absorbed by green growing things and by the sea. It is the most prominent greenhouse gas that traps heat radiated into the atmosphere.

Carbon monoxide (CO): Colorless, odorless gas that is toxic if breathed in high concentrations over an extended period. Listed as a criteria air pollutant under Title I of the Clean Air Act (CAA).

Carnivore: Any flesh-eating or predatory organism.

Carrying capacity: Maximum density of wildlife or population of a specific species that a particular region can sustain without deterioration of the habitat or hindering future generations' ability to maintain the same population.

Catch and release: Practice within recreational fishing intended as a conservation measure in which captured fish are unhooked and returned to the water before experiencing serious exhaustion or injury.

Cations: Ions that carry a positive charge (e.g., sodium, magnesium, calcium, iron, and aluminum).

Cenozoic age: Era extending from about 65 million years ago to the present.

Census block group: Geographic entities consisting of groups of individual census blocks. Census blocks are grouped together so that they contain between 250 and 550 housing units.

Channel: Natural or artificial watercourse with a definite bed and banks to confine and conduct continuously or periodically flowing water.

Channel margin bar: Narrow sand deposits that continuously or discontinuously line the riverbank.

Chemocline: Boundary or gradient between water masses of different chemical composition (e.g., salinity).

Chironomid: Group of two-winged flying insects that live their larval stage underwater and emerge to fly about as adults.

Cladocera: An order of small crustaceans commonly called water fleas.

Cladophora: Filamentous green alga that is very important to the food chain in the Colorado River below Glen Canyon Dam.

Class I scenic resource: Classification of areas within Glen Canyon that have outstanding scenic quality such as intricately carved landscapes, unique canyons, and unique geological features.

Class II scenic resource: Classification of an area within Glen Canyon that has superior quality or a diversity of form and color.

Clay: Fine-grained soil, rock, or mineral fragment that has a diameter of less than 0.002 millimeters (mm). Clay is often made up of one or more minerals (e.g., hydrous aluminum phyllosilicates, sometimes with iron, magnesium, alkali metals, alkaline earths, and other cations) with traces of metal oxides and organic matter.

Clean Air Act (CAA): Comprehensive federal law that regulates air emissions. This act establishes national ambient air quality standards (NAAQS) that protect public health and the environment. Under this act, construction and operating permits, as well as reviews of new stationary emissions sources and major modifications to existing sources, are required. It further requires facilities to comply with emission limits or reduction limits stipulated in State Implementation Plans (SIPs) and prohibits the federal government from approving actions that do not conform to SIPs. Originally passed in 1963, the national air pollution control program is actually based on the 1970 version of the law. The 1990 CAA amendments, in large part, were intended to deal with previously unaddressed or under-addressed problems such as acid rain, ground level ozone, ozone depletion, and air toxics.

Clean Water Act (CWA): Establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under the CWA, the U.S. Environmental Protection Agency (EPA) has implemented several pollution control programs, such as setting wastewater standards for industry and requiring National Pollutant Discharge Elimination System (NPDES) permits for discharges of effluents to surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. “Clean Water Act” became the Act’s common name with amendments in 1972.

Climate change: Significant and lasting change in the statistical distribution of weather conditions and patterns over periods of years, ranging from decades to millions of years.

Clovis technological complex: A widespread, distinctive early Paleoindian culture defined by a distinct form of fluted stone projectile points named for Clovis, New Mexico, the city near which they were found. Clovis technology dates to around 13,500 years ago.

Cobble: Loose particles of rock or mineral (sediment) that range in size from 64 to 256 mm in diameter. Cobbles are larger than gravel, but smaller than boulders.

Code of Federal Regulations (CFR): Codification and compilation of the general and permanent rules published in the *Federal Register* by the departments and agencies of the United States Federal Government. It is divided into 50 subject matter titles that represent broad areas subject to federal regulation. Each title contains one or more individual volumes, which are updated once each calendar year, on a staggered basis.

Cohort: A group of fish that were generated in the same spawning season and are born at the same time.

Coldwater fish: Species of fish that require relatively cold water (50–60°F, or 10–15°C) to survive. Cold water can hold more dissolved oxygen than warm water, so these species generally inhabit deeper lakes and ponds in northern regions, spring-fed streams and lakes with a constant cold water supply, or lakes in high altitudes that are cold. Rainbow trout is an example of a coldwater species.

Colorado River Basin: All areas that drain to the Colorado River and its tributaries.

Colorado River Basin Project Act of 1968 (CRBPA): Act that authorized construction of a number of water development projects, including the Central Arizona Project (CAP), and required the Secretary of Interior to develop the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, or Long-Range Operating Criteria (LROC).

Colorado River Basin Salinity Control Act: Law enacted by Congress in 1974 that directed the Secretary of the Interior to proceed with a program to enhance and protect the quality of water available in the Colorado River for use in the United States and Republic of Mexico.

Colorado River Compact of 1922: Provides for the equitable division and apportionment of the use of the waters of the Colorado River System between the Upper Basin and Lower Basin states.

Colorado River Ecosystem: Community of aquatic, riparian, and terrestrial fauna and flora of the Colorado River mainstream corridor and its tributaries, along with that system's processes and environments. In general, the CRE encompasses the Colorado River primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park and includes the area where the Glen Canyon Dam operations impact physical, biological, recreational, cultural, and other resources.

Colorado River Simulation System (CRSS): Operational model of the Colorado River Basin based on a monthly time step.

Colorado River Storage Project Act (CRSPA) of 1956: Authorized comprehensive development of the water resources of the Upper Basin states (Colorado, New Mexico, Utah, and Wyoming) by providing for long-term regulatory storage of water, including construction of Glen Canyon Dam, to meet the entitlements of the Lower Basin states (Arizona, California, and Nevada).

Commercial river trip: Trip organized by a boating company that conducts tours and recreational outings for paying passengers.

Community: All members of a specified group of species present in a specific area at a specific time; a group of people who see themselves as a unit.

Compact: Agreement between states apportioning the water of a river basin to each of the signatory states.

Compact point: Lee Ferry, Arizona, the reference point designated by the Colorado River Compact dividing the Colorado River into two sub-basins, the Upper Basin and the Lower Basin.

Concentration: Amount of a chemical in a particular volume or weight of air, water, soil, or other medium.

Concrete-arch dam: Dam design often used in a narrow, steep-sided rock canyon with curvatures in both horizontal and vertical directions. The safety of an arch dam is dependent on the strength of the side wall abutments and the strength and elasticity of the concrete used in its construction.

Conductivity: Measure of the ability of water to pass an electrical current. Conductivity is an indicator of the amount of dissolved salts in a stream, and is often used to estimate the amount of total dissolved solids (TDS) rather than measuring each dissolved constituent separately. Conductivity in water is also affected by temperature.

Confluence: Meeting point of two or more rivers.

Consolidated Decree: Entered by the United States Supreme Court on March 27, 2006, in the case of Arizona v. California, 547 U.S. 150 (2006). In 1963, the Supreme Court reached a Decision in the case of Arizona v. California. The 1964 Supreme Court Decree in the case of Arizona v. California implemented the 1963 Decision. This 1964 Supreme Court Decree was supplemented over time after its adoption and the Supreme Court entered a Consolidated Decree in 2006 incorporating all applicable provisions of the earlier-issued Decisions and Decrees.

Consumptive water use: Total amount of water used by vegetation, human activities, and natural cycling processes (e.g., evaporation, transpiration, incorporation) that is not available for other uses within the system.

Continental climate: A climate lacking marine influence and characterized by more extreme temperatures than marine climates; therefore, it has a relatively high annual temperature range for its latitude.

Continental Divide: Drainage divide that separates the Atlantic and Pacific watersheds of North America.

Contingent valuation: Survey method asking for the maximum values that users would pay for access to a particular activity.

Control area: Part of a power system, or a combination of systems, to which a common electrical generation control scheme is applied.

Convection: Motions in a fluid that result in the transport and mixing of the fluid’s properties.

Cooperating Agency: With respect to the National Environmental Policy Act of 1969, as amended (NEPA), process, an agency that has jurisdiction by law or special expertise concerning an aspect of a proposed federal action, and that is requested by the lead agency to participate in the preparation of an Environmental Impact Statement.

Coordinated operation: Generally, the operation of two or more interconnected electrical systems to achieve greater reliability and economy. As applied to hydropower resources, the operation of a group of hydropower plants to obtain optimal power benefits with due consideration for all other uses.

Copepods: Small crustaceans that live in virtually all marine and freshwater habitats.

Cosmology: Set of beliefs regarding the origin and structure of the universe.

Council on Environmental Quality (CEQ): Established by NEPA, CEQ regulations (40 CFR Parts 1500–1508) describe the process for implementing NEPA, including preparation of Environmental Assessments and EISs, and the timing and extent of public participation.

Cover: Vegetation, rocks, or other materials used by wildlife for protection from predators or weather.

Creel census: Angler survey to collect data on the harvest, size, and distribution of various species of fish.

Criteria air pollutants: Six common air pollutants for which NAAQS have been established by the EPA under Title I of the CAA. Included are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), and lead (Pb). Standards were developed for these pollutants on the basis of scientific knowledge about their health effects.

Critical habitat: Specific areas within the geographical area occupied by the species that have physical or biological features essential to the conservation of a listed endangered or threatened species and may require special management considerations or protection. These areas are legally designated via *Federal Register* notices.

Cross-sectional area: Area of a stream, channel, or waterway, usually measured perpendicular to the flow.

Crustacean: Aquatic animals with hard external skeletons and segmented limbs, belonging to the class Crustacea; includes cladocerans, shrimp, crayfish, fairy shrimp, isopods, amphipods, lobsters, and crabs.

Cubic foot per second (cfs): As a rate of streamflow, a cubic foot of water passing a reference section in 1 second. A measure of a moving volume of water (1 cfs = $0.0283\ m^3/s$).

Cultural modification: Any human-caused change in the land form, water form, or vegetation, or the addition of a structure that creates a visual contrast in the basic elements (e.g., form, line, color, or texture) of the naturalistic character of a landscape.

Cultural property: The tangible evidence or expression of cultural heritage such as works of art, buildings, or their ruins.

Cultural resource: Any sites, districts, buildings, structures, objects, or features significant in history, architecture, archeology, culture, or science. Also, Native American sacred sites or special use areas that provide evidence of the prehistory and history of a community.

Cumulative impact: Impact assessed in an EIS that results from the incremental impacts of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (federal or nonfederal), private industry, or individual undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

Cyanobacteria: Blue-green algae, prokaryotic, photosynthetic organisms that generally have a blue-green tint and lack chloroplasts.

Cyprinids: Largest family of freshwater fish, commonly called the carp family or minnow family.

D

Daily fluctuation: Difference between daily maximum and minimum releases from the dam. These scheduled fluctuations are used to maximize efficiency of power generation.

Dead capacity: Reservoir capacity from which stored water cannot be evacuated by gravity. At Glen Canyon Dam, this is the Lake Powell storage below the river outlet works openings at an elevation of 3,374 ft (1,028 m).

Debris fan: Sloping mass of water and debris, including boulders, cobbles, gravel, sand, silt, clay, and organic material (e.g., tree limbs), formed by debris flows at the mouth of a tributary.

Debris flow: Mixture of rocks, sediment, and organic material containing less than 40% water by volume that flows downslope under the force of gravity (e.g., flash flood).

Defoliation: Process by which a plant, shrub, or tree loses its leaves. Possible causes include insect activity, disease, chemicals, or the coming of autumn.

Degradation: Process wherein elevation of streambeds, floodplains, and sandbars is lowered by erosion. The opposite of aggradation.

Delivery: The amount of water delivered to the point of use.

Delta: Flat alluvial area formed at the mouth of some rivers and streams (e.g., Colorado River) where the mainstream flows into a body of standing water, such as a sea or lake (e.g., Lake Powell or Lake Mead), and deposits large quantities of sediment.

Depletion: Loss of water from a stream, river, or basin resulting from consumptive use.

Deposition: Settlement of material out of the water column and on to the streambed or flooded areas. Occurs when the energy of flowing water is unable to support the load of suspended sediment.

Desiccation: Process of drying out.

Desired future condition (DFC): Measurable target or value, established for any resource area that is of interest to managers; provides a reference point for evaluating treatment effectiveness and the need to implement additional treatments or management actions.

Detritivore: An organism that feeds on dead and decomposing matter.

Detritus: Loose natural materials, such as rock fragments or organic particles, that result directly from disintegration of rocks or organisms.

Diatom: Microscopic, single-celled, or colonial algae having cell walls of silica.

Diel fluctuations: Changes or fluctuations that occur in a 24-hour period that usually includes a day and the adjoining night.

Diptera: Order of insects that includes all true flies.

Direct effect (impact): Effect on the environment caused by an action; occurs at the same time and place as the initial action.

Direct impact: See *direct effect*.

Discharge (flow): Volume of water that is released from the dam at any given time or that passes a given point within a given period of time. Usually expressed in cubic feet per second (cfs).

Dispatch: The operating control of an integrated electric system whose job it is to (1) assign generation to specific generating plants and other sources of electric supply to effect the most reliable and economical supply as the total of the significant area loads rises or falls; (2) control operations and maintenance of high-voltage lines, substations, and equipment, including administration of safety procedures; (3) operate the interconnection; and (4) schedule energy transactions with other interconnected electric utilities.

Dissolved oxygen (DO): Amount of free oxygen found in water expressed as a concentration, milligrams per liter (mg/L), or as percent saturation (the amount of oxygen the water holds compared to the maximum amount it could absorb at that temperature). Low DO levels adversely affect fish and other aquatic life. The ideal dissolved oxygen for fish life is between 7 and 9 mg/L; most fish cannot survive when DO falls below 3 mg/L.

Dissolved solids: See *total dissolved solids (TDS)*.

Divert: To direct a flow away from its natural course.

Downstream: Situated or moving in the direction of a stream or river's current.

Drainage: Process of removing surface or subsurface water from a soil or area.

Drawdown: Lowering of a reservoir's water level; process of depleting reservoir or groundwater storage.

Drift: Food organisms dislodged and moved by river current. Can include algae, plankton, invertebrates, and larval fish.

Driftwood: Remains of trees that have been washed onto a shoreline by the action of winds, tides, or waves.

Drought: Period of unusually persistent dry weather that persists long enough to cause serious problems such as crop damage and/or water supply shortages.

Dune: Wind-deposited sand body, usually a rounded hill, ridge, or mound.

E

Ecological resource: Animals, plants, and the habitats in which they live, which may be land, air, or water.

Ecological restoration: Process of assisting in the recovery of an ecosystem that has been degraded, damaged, or destroyed.

Ecology: The relationship between living organisms and their environments.

Ecoregion: A geographically distinct area of land that is characterized by a distinctive climate, ecological features, and plant and animal communities.

Ecosystem: Complex system composed of a community of fauna and flora and that system's chemical and physical processes and environment.

Ecosystem management: Approach to natural resource management that seeks an understanding of the interrelationships among important physical, chemical, biological, cultural, political, and social processes in order to conserve resources and sustain ecosystems to meet both ecological and human needs of current and future generations.

Ectoparasitic: Living on the exterior of another organism, the host, obtaining nourishment from the latter.

Eddy: Current of water moving against the main current in a circular pattern. See *recirculation zone*.

Effect: Environmental consequences (the scientific and analytical basis for comparison of alternatives) that occur as a result of a proposed action. See *direct effect* and *indirect effect*.

Efficiency: Ratio of useful energy output to total energy input, usually expressed as a percentage.

Electric power system: Physically connected electric power generating, transmission, and distribution facilities operated as a unit under one control.

Electrical demand: Energy requirement placed upon a utility's generation at a given instant or averaged over any designated period of time.

Electrofishing: Application of a direct electric current to attract and temporarily immobilize fish for easy capture. See *mechanical removal*.

Embayment: a recess or an indentation in a shore line that forms an area with low flow.

Emergent marsh plants: Plants that are rooted in soil with basal portions that typically grow beneath the surface of the water but whose leaves, stems, and reproductive organs are above the water.

Emissions: Substances that are discharged into the air from industrial processes, vehicles, and living organisms.

Empirical: Based on experimental data rather than theory.

Encroachment: Act of advancing, intruding, or extending beyond established, usual, or proper limits.

Endangered species: Species or subspecies (plant or animal) whose survival is at risk of extinction throughout all or a significant portion of its range because it is either few in numbers or threatened by changing environmental or predation parameters. Requirements for declaring a species endangered are found in the ESA.

Endangered Species Act of 1973 (ESA): Provides a federal program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. Requires consultation with the FWS and/or the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service to determine whether endangered or threatened species or their habitats will be affected by a proposed activity and what, if any, mitigation measures are needed to address the impacts.

Endemic: Native to and restricted to a particular geographic region.

Energy: Electric capacity generated and/or delivered over time; usually measured in kilowatt-hours.

Environmental Assessment (EA): Concise public document that a federal agency prepares under NEPA to provide sufficient evidence and analysis to determine whether a proposed action, or its alternatives, may have significant environmental effects on the human environment. In general, an EA must include brief discussions on the need for the proposal, the alternatives, the environmental impacts of the proposed action and alternatives, and a list of agencies and persons consulted. If significant effects may occur, an EIS is prepared instead of an EA.

Environmental Impact Statement (EIS): Detailed document required of federal agencies under NEPA for major proposals or legislation that will or could significantly affect the environment. An EIS is prepared with public participation and must disclose significant issues and impacts on the human environment that may result from the proposed action or its alternatives. An EIS includes the following: the environmental impact of the proposed action; any adverse impacts that cannot be avoided by the proposed action; alternative courses of action; relationships between local short-term use of the human environment and the maintenance and enhancement of long-term productivity; and a description of the irreversible and irretrievable commitment of resources that would occur if the action were accomplished.

Environmental justice: Fair treatment of people of all races, cultures, incomes, and educational levels with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Ephemeral stream: Stream that flows briefly only in direct response to precipitation and whose channel is, at all times, above the water table.

Epilimnion: Top layer of a thermally stratified lake or reservoir that exhibits essentially uniform warmer temperature. See *stratification*.

Epiphyte: A plant that derives its moisture and nutrients from the air and rain and grows on another plant for support.

Equalization flow: Dam releases made to balance water storage between Lake Powell and Lake Mead. Pursuant to the Interim Guidelines, these flow events are carried out if (1) the end of the water year storage forecast for Lake Powell is greater than that of Lake Mead; and (2) the storage forecast for the end of the water year in the Upper Basin reservoirs is greater than the quantity of storage required by Section 602(a) of the CRBPA (602[a] storage) for that same date.

Equalization tier: Operation elevation that applies when Lake Powell's projected January 1 elevation is above the elevation in the equalization table of the Interim Guidelines. The tier provides for Lake Powell releases of more than 8.23 maf during the water year until the content of the lakes equalizes or certain elevations are attained.

Erosion: Gradual destruction or wearing away of a material (e.g., rock or sand) or object (e.g., beach) by water, wind, or other natural agents.

Ethnobotany (ethnobotanical): The plant lore and agricultural customs of a people; the study of such lore and customs.

Ethnohistory: The use of both historical and ethnographic data such as maps, music, paintings, photography, folklore, and oral tradition to understand a culture on its own terms and according to its own cultural code.

Euphotic zone: The superficial layer of a water body within the range of effective light penetration for photosynthesis.

Eutrophication: Enrichment of a body of water as a result of high concentrations of minerals and organic nutrients (especially nitrogen and phosphorus) that stimulate and promote the proliferation of aquatic plant life, thus reducing the dissolved oxygen content of the water.

Evaporation: Water vapor losses to the atmosphere from land areas, bodies of water, and all other moist surfaces.

Evapotranspiration: Sum of water transpired or used by plants and evaporated from surfaces (e.g., water bodies and soils) in a specific time period; usually expressed in depth of water per unit area.

Exceedance: Measured level of an air pollutant that is higher than the national or state ambient air quality standards. Also applies to water volume, flow, or energy generation that is above a particular percentage (exceedance level).

Excess capacity: Power generation capacity available on a short-term basis in excess of the firm capacity available through long-term contracts.

Executive Order (EO): President's or governor's directive or declaration that implements or interprets a federal statute, a constitutional provision, or a treaty. It has the force of law and is usually based on existing statutory powers; requires no action by Congress or a state legislature.

Existence value: Value people place on simply knowing an area or feature continues to exist in a particular condition.

Exotic species: Nonnative plant or animal deliberately or accidentally introduced into a new habitat where it is able to reproduce and survive.

Experimental flow: Investigational releases (e.g., high-flow experiments) that are designed to explore, test, and assess the relationships between dam operations and downstream resources in and along the Colorado River within the Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA).

Experimental population: Specific reintroduced populations of listed species under the ESA. The FWS determines whether an experimental population is "essential" or "nonessential" to the continued existence of the species.

Exposure: Contact of an organism with a chemical, radiological, or physical agent.

Extinct species: Species having no living members, such that it is no longer in existence.

Extirpated species: Species that no longer exists in a given region or area.

Extirpation: Elimination of a species or subspecies from a particular area, but not from its entire range.

F

Fan-eddy complex: An assemblage of geomorphic features created by a debris fan that projects into a stream or river and creates an area of recirculation (eddy) just downstream of the debris fan.

Fauna: Animals in a specific region or habitat, considered as a group.

Feature: Large, complex artifact, or part of a site, such as a hearth, cairn, housepit, rock alignment, or activity area.

Fecal coliform bacteria: Group of organisms common to the intestinal tracts of humans and animals. The presence of fecal coliform bacteria in water is an indicator of pollution and of potentially dangerous bacterial contamination.

Fecundity: Number of produced eggs or offspring; reproductive capability.

Federal Register: Official daily publication for rules, proposed rules, and notices of federal agencies and organizations, as well as executive orders and other presidential documents; published by the Office of the Federal Register, National Archives and Records Administration (NARA).

Filamentous algae: Plant that forms a greenish mat on the water surface.

Finding of No Significant Impact (FONSI): NEPA document issued by a federal agency briefly presenting the reasons why an action, not otherwise excluded, will not have a significant effect on the human environment if implemented. This finding is based on the results of an EA and other factors in the public planning record for a proposed action.

Fine sediment: Soil particles, typically defined as less than 1–2 mm in diameter (e.g., clay and silt), that are naturally filtered from coarser fractions and carried by water.

Firm energy or power: Uninterruptible energy and power guaranteed by the supplier to be available at all times except for reasons of uncontrollable forces or continuity of service provisions.

Fishery: Specified waters or area where fish or other aquatic animals are reared and caught.

Flash flood: Sudden high-flow event through a valley, canyon, or wash, following a short-duration, high-intensity rainfall.

Flatwater boating: Form of low-speed boating (e.g., canoeing or kayaking) that relies on flat waters (e.g., lakes, gorges, or slow-moving rivers), as opposed to rapids or white water.

Flood: Relatively high flow or inundation of water, as measured by either gage height or discharge quantity, that overtops the natural or artificial banks in any reach of a river and threatens or causes damage.

Flood Control Act of 1944: Act authorizing the construction of certain public works on rivers and harbors for flood control and other purposes.

Flood control capacity: Reservoir capacity assigned for the sole purpose of regulating flood inflows to reduce flood damage downstream.

Flood control pool: Reservoir volume above the active conservation and joint-use pool that is reserved for flood runoff and then evacuated as soon as possible to keep that space in readiness for the next flood. See *reservoir capacity*.

Flood flows: In this report, water releases from Glen Canyon Dam in excess of powerplant capacity (i.e., 31,500 cfs).

Floodplain: Mostly level, low-lying land adjacent to a water body that is subjected to inundation and submersion during high flow or rainfall events. The relative elevations of floodplain areas determine their frequency of flooding, which ranges from rare, severe, storm events to flows experienced several times a year.

Flora: Community of plants in a specific region or habitat, considered as a group.

Flow: Volume of water passing a given point per unit of time. See *instream flow requirements*, *minimum flow*, *peak flow*, *ponding flow*, *spike flow*, and *steady flow*.

Flow regime: Flow variation through time resulting from operations of the Glen Canyon Dam.

Fluctuating flows: Water released from Glen Canyon Dam that varies in volume, usually within a given range (e.g., 1,000 to 31,500 cfs), over a 24-hour period.

Fluctuation zone: Area of a sandbar or vegetation zone that is within the range of fluctuating flow.

Fluvial: Pertaining to a river or stream; indicates the presence or interaction of a river within an area or landform.

Fluvial geomorphology: Study and examination of stream and river channels, both in their natural setting and their response to human-induced changes in a watershed. Includes the processes that operate in river systems and the landforms they create or have created.

Folsom technological complex: A widespread, distinctive early Paleoindian culture defined by a distinct form of fluted stone projectile points named for Folsom, New Mexico, the city near which they were found. Folsom technology dates to between 11,500 and 10,000 years ago.

FONSI: See *Finding of No Significant Impact*.

Food chain: Succession of organisms in a community in which food energy is transferred from one organism to another as each consumes a lower member and in turn is consumed by a higher member.

Food web: Complex system or network of interrelated and interdependent food chains that describes how food energy is passed throughout an ecological community.

Food base: Substances or materials that provide living things with the nutrients they need to provide energy, grow, and sustain overall life.

Forage fish: Generally, small fish that produce prolifically and are consumed by predators.

Forced outage: Nonscheduled shutting down of a generating unit or other facility for emergency or other unforeseen reasons.

Forebay: Impoundment immediately above a dam or hydroelectric powerplant intake structure.

Fossil fuel: An energy source formed in the Earth's crust from decayed organic material. Common fossil fuels are petroleum, coal, and natural gas.

Fragmentation: Process by which habitats are increasingly subdivided into smaller units, resulting in their increased insularity as well as losses of total habitat area.

Fry: Life stage of fish between the egg and fingerling stages.

Fugitive dust: The dust released from any source other than a definable point source such as a stack, chimney, or vent. Sources include construction activities, storage piles, and roadways.

Full pool: Volume of water in a reservoir at maximum design elevation. At Lake Powell this is at an elevation of 3,700 ft (1,130 m). Total volume is 27 maf; this volume is decreasing as the lake fills with sediment.

G

Gage: Device or instrument used for measuring or testing.

Gated spillway: Overflow section of dam restricted by use of gates that can be operated to control releases from the reservoir to ensure the safety of the dam.

Gaging station: Specific location on a river or stream where systematic observations and measurements of hydrologic data are obtained through mechanical or electrical means.

Generation (power): Process of producing electrical energy by transforming other forms of energy. Also, the amount of electric energy produced.

Generator: Machine that converts mechanical energy into electrical energy.

Geology: Science that deals with the study of the materials, processes, environments, and history of the Earth, including rocks and their formation and structure.

Geomorphology: Geological study of the configuration and evolution of landforms and earth features.

Gigawatt-hour (GWh): One billion watt-hours of electrical energy.

Glen Canyon Dam: Second highest concrete arch dam in the United States. Constructed to harness the power of the Colorado River to provide for the water and power needs for people in the western United States.

Glen Canyon Dam Adaptive Management Program (GCDAMP): Provides an organization and process for cooperative integration of dam operations, downstream resource protection and management, and monitoring and research information, as well as to improve the values for which the GCNP and GCNRA were established.

Glen Canyon Environmental Studies (GCES): Program started by the Bureau of Reclamation in 1982 to collect scientific evidence on the positive and negative impacts on downstream environmental and cultural resources as a result of daily fluctuating releases from the dam.

Glen Canyon National Recreation Area (GCNRA): Area that encompasses hundreds of square miles from Lees Ferry in Arizona to the Orange Cliffs of southern Utah for water-based and backcountry recreation.

Global warming: Increase in the near-surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural influences, but the term is today most often used to refer to the warming that many scientists predict will occur as a result of increased anthropogenic emissions of greenhouse gases.

Gradient: See *slope*.

Grand Canyon Monitoring and Research Center (GCMRC): Science provider for the GCDAMP. Operated by the U.S. Geological Survey, the GCMRC provides relevant scientific information about the status and trends of natural, cultural, and recreational resources found in those portions of the GCNP and GCNRA affected by Glen Canyon Dam operations.

Grand Canyon National Park (GCNP): A National Park since 1919, the area contains unique combinations of erosional forms. It is 277 river miles long and up to 18 miles wide. The area encompasses 1,218,375 acres and lies on the Colorado Plateau in northwestern Arizona, with land that is semiarid and consists of raised plateaus and structural basins.

Grand Canyon National Park Enlargement Act: An act of Congress enacted in 1975 to further protect the Grand Canyon by enlarging the park in the state of Arizona.

Grand Canyon Protection Act of 1992 (GCPA): Directs the operation of Glen Canyon Dam in compliance with existing law to protect, mitigate adverse impacts on, and improve the values for which the GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use.

Green algae: Members of the plant phylum Chlorophyta, which possess the green pigment chlorophyll that they use to capture light energy to fuel the manufacture of sugars. This diverse group of algae consists primarily of freshwater eukaryotic organisms, which serve as food and oxygen sources for other aquatic organisms.

Greenhouse effect: Increasing mean global surface temperature of the Earth caused by gases in the atmosphere (including carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbon). The greenhouse effect allows solar radiation to penetrate, but also absorbs infrared radiation returning to space.

Greenhouse gases (GHGs): Heat-trapping gases in the atmosphere that contribute to global warming and temperature gain near the Earth's surface. Natural and human-made GHGs include water vapor, carbon dioxide, methane, nitrogen oxides, ozone, and fluorinated gases (e.g., chlorofluorocarbons).

Gross generation: Total amount of electrical energy produced by a generating station or stations, measured at generator terminals.

Groundwater: Supply of water found beneath the Earth's surface, usually in porous rock formations (i.e., aquifers), which may supply wells and springs.

Gully: Landform that erodes sharply into soil, typically on a hillside; caused by running water. Gullies are similar to ditches or small valleys, but they are typically only 3 to 30 ft (0.9 to 9 m) wide and deep.

H

Habitat: Area or place, including physical and biotic conditions, where a plant or animal lives.

Hanging garden: Unique biological feature formed when spring water flows through cracks in the sandstone and seeps out through the canyon walls, allowing plants to grow vertically.

Harvest: In a recreational fishery, refers to numbers of fish that are caught and kept.

Head: Height of water above a specified point.

Headwater: Source and upper part of a stream or lake inflow.

Heavy metal: Metallic elements with high atomic weights (e.g., lead, mercury, cadmium, chromium, and arsenic) that are generally toxic in relatively low concentrations to plant and animal life.

Herbaceous: The plant strata that contain soft, not woody, stemmed plants that die to the ground in winter.

Herbivore: Animal that feeds on plants.

Herpetofauna: General grouping for reptiles and amphibians.

High flow: Pulses or temporary influxes of water that typically occur after periods of precipitation and are contained within the natural banks of the river (i.e., do not cause flooding). In a river, these events can lead to a temporary reduction in downstream temperature and increases in salinity, dissolved oxygen, and turbidity. High flows suspend and deliver large amounts of sediment and organic matter downstream, which can redeposit on sandbars and beaches. They can also restore and enhance riparian vegetation and can prevent undesirable vegetation from invading river channels. In addition, high-flow events can work to reshape and maintain native fish habitats, stimulate food base production, and suppress numbers of nonnative fish.

High-flow experiment (HFE): High-volume test releases (31,500 to 45,000 cfs) from the Glen Canyon Dam that are performed under sediment-enriched conditions. HFEs are specifically designed to benefit downstream resources; this includes maintaining and rebuilding sandbars and beaches in downstream reaches. Also referred to as a high-flow test.

High-flow test: See *high-flow experiment*.

Historic: The time period after the appearance of written records. In the New World, this generally refers to the time period after the beginning of European settlement at approximately 1600 AD.

Historic property: Any prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion in, the *National Register of Historic Places* maintained by the Secretary of the Interior. They include artifacts, records, and remains that are related to and located within such properties.

Historic resource: In the United States, material remains and the landscape alterations that have occurred since the arrival of Europeans.

Human environment: Natural and physical environment and the relationship of people with that environment including all combinations of physical, biological, cultural, social, and economic factors in a given area.

Hydraulic: Powered by water.

Hydroelectric plant: Electric powerplant using falling water as its motive force.

Hydroelectric power: Electricity produced by water.

Hydrogen sulfide (H_2S): A colorless, flammable, and extremely hazardous gas that occurs naturally in crude petroleum, natural gas, and hot springs.

Hydrograph: Graph showing, for a given point in a stream, the discharge, stage, velocity, or other property of water with respect to time.

Hydrologic budget: An accounting of the inflow to, outflow from, and storage change in a hydrologic unit such as an aquifer or drainage basin.

Hydrologic cycle: Continuous circulation of water in all of its phases (gas, liquid, solid) from the atmosphere to Earth by precipitation, and from Earth to the atmosphere by evaporation and transpiration. The land phase includes infiltration, runoff, and exchange between surface water and groundwater.

Hydrology: Science dealing with the occurrence, properties, distribution, circulation, and transport of water, including groundwater, surface water, rain, and snow.

Hydropower: See *hydroelectric power*.

Hypolimnetic: Pertaining to the lower, colder portion of a lake or reservoir, which is separated from the upper, warmer portion (epilimnion) by the thermocline.

Hypolimnion: Non-circulating bottom layer of a thermally stratified lake or reservoir that exhibits essentially uniform colder temperature and low dissolved oxygen.

Hypoxia: depressed levels of dissolved oxygen in water, usually resulting in decreased metabolism.

I

Igneous rock: A crystalline rock formed by the cooling and solidification of molten or partly molten material (magma). Igneous rock includes volcanic rock (rock solidified above the Earth's surface) and plutonic rock (rock solidified at considerable depth).

Impact: Effect, influence, alteration, or imprint caused by an action. See *adverse impact*, *cumulative impact*, *direct impact*, and *indirect impact*.

Impoundment: Body of water created by a dam, dike, floodgate, or other barrier.

Inactive capacity: Reservoir capacity that can be released from the dam but is normally not available (i.e., for power generation) because of operating agreements or physical restrictions. At Glen Canyon Dam, this is the reservoir storage above the river outlet works openings at elevation 3,374 ft (1,038 m) and below the penstock openings at elevation 3,490 ft (1,064 m), which is about 3.9 maf.

Indian trust assets: Lands, natural resources, or other assets held in trust or restricted against alienation by the United States for Native American Tribes or individual Native Americans.

Indian trust resource: Those natural resources, either on or off Indian lands, retained by or reserved by or for Indian Tribes through treaties, statutes, judicial decisions, and Executive Orders, which are protected by a fiduciary obligation on the part of the United States.

Indigenous: Native to an area.

Indirect effect (impact): Effect that occurs away from the place of action with effects that are related to, but removed from, a proposed action by an intermediate step or process. An example would be changes in surface-water quality resulting from soil erosion at construction sites.

Indirect impact: See *indirect effect*.

Inflow: Amount or rate of water flowing into a body of water. In this report, the water flowing into Lake Powell from the Colorado River and/or its tributaries; or water entering the Colorado River from tributaries between Glen Canyon Dam and Lake Mead; or water flowing into Lake Mead, mainly from the Colorado River.

Infrastructure: Basic facilities, utilities, services, and transportation framework needed to meet public and administrative needs for the functioning of an organization, system, or community.

In-situ: In its natural position or place; unmoved, unexcavated, remaining at the site or subsurface.

Insolation: Solar energy that is received on a given surface area during a given time.

Instream flow requirements: Amount of water flowing through a stream course needed to sustain instream values.

Intake: Structure in a dam, reservoir, or river through which water can be drawn into an outlet pipe or waterway.

Interconnected systems: System consisting of two or more individual power systems normally operating with connecting tie lines.

Interflow: Lateral movement of water in the upper layer of soil.

Interim shortage criteria/interim guidelines: Operational guidelines and coordinated reservoir management strategies (established in 2007) to address operations of Lake Powell and Lake Mead, particularly under drought and other low reservoir conditions. These criteria also provide a greater degree of certainty to U.S. Colorado River water users and managers of the Colorado River Basin by detailing information on when, and by how much, water deliveries will be reduced under specified reservoir conditions.

Intermittent stream: Stream that flows only at certain times of the year when the ground-water table is high; occasionally is dry or reduced to a pool stage when losses from evaporation or seepage exceed the amount of inflow.

Inundate: To cover with impounded waters or floodwaters.

Invasive species: Nonnative plant or animal, including noxious and exotic species, that is an aggressive colonizer and can out-compete other species. Their introduction causes or is likely to cause economic or environmental harm or harm to human health.

Invertebrate: Animal without a spinal cord, usually replaced by a hard exoskeleton or shell. Examples include insects, spiders, crayfish, snails, or clams.

Ion: Atom or molecule that carries either a positive or negative electrical charge.

Irretrievable commitments of resources: Those resources that are lost or lose value for a period of time and cannot be restored as a result of an action, such as temporary loss of power productivity due to of modified operations.

Irreversible commitments of resources: Those resources that cannot be regained, restored, or returned to their original condition within a reasonable time frame, such as the extinction of a species.

Irrigation district: A cooperative, self-governing public corporation set up as a subdivision of the state government, with definite geographic boundaries; organized and having taxing power to obtain and distribute water for irrigation of lands within the district; created under the authority of a state legislature with the consent of a designated fraction of the landowners or citizens.

J

Jeopardy opinion: FWS or NMFS opinion that an action is likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of critical habitat.

Jet tube: A Glen Canyon Dam outlet that releases water below the level of penstocks. Four jet tubes with a combined release capacity of 15,000 cfs are not equipped with generation capability, but allow for a total release of about 45,000 cfs when used in combination with maximum releases from each of the eight penstocks.

Juvenile: Young organism older than 1 year but not having reached reproductive age.

K

Kaibab formation: The rock that makes the canyon rims and is the youngest of the Grand Canyon’s geologic layers.

Kilovolt (kV): 1,000 volts (V).

Kilowatt (kW): Unit of electric power capacity equal to 1,000 watts (W), or about 1.34 horsepower (HP).

Kilowatt-hour (kWh): Basic unit of electric energy equaling an average of 1 kW of power applied over 1 hour.

L

Lake Mead National Recreation Area (LMNRA): American's first national recreation area; encompasses Lake Mead and Lake Mohave.

Lake Powell: Reservoir created by the completion of the Glen Canyon Dam on the Colorado River in 1963.

Landform: Any feature of the Earth's surface having a distinct shape and origin. Landforms include major features (such as continents, ocean basins, plains, plateaus, and mountain ranges) and minor features (such as hills, valleys, slopes, drumlins, and dunes).

Landmark (historic): Significant historic places designated by the Secretary of the Interior because they possess exceptional value or quality in illustrating or interpreting the heritage of the United States.

Landmark (visual): Type of reference point external to the observer. Usually a simply defined physical object that can be seen from many angles and distances over the tops of smaller elements and used as a radial reference.

Landscape: Traits, patterns, and structure of a specific geographic area including its biological composition, its physical environment, and its anthropogenic or social patterns.

Larva, larvae (pl.): The immature stage between the egg and pupa of insects having complete metamorphosis where the immature differs radically from the adult (e.g., caterpillars, grubs).

Larval fish: First life stage of fish after hatching. Larvae are not able to feed themselves, and carry a yolk-sac that provides their nutrition.

Latitude: Angular distance north or south of the equator, measured in degrees.

Law of the River: As applied to the Colorado River, the collective set of documents that apportions the Colorado River waters and regulates the use and management of the Colorado River among the seven Basin States and Mexico. It is comprised of numerous operating criteria, regulations, and administrative decisions included in federal and state statutes, interstate compacts, court decisions and decrees, an international treaty, and contracts with the Secretary of the Interior.

Lead (Pb): A gray-white metal that is listed as a criteria air pollutant. Health effects from exposure to lead include brain and kidney damage and learning disabilities. Sources include leaded gasoline and metal refineries.

Lead agency (or agencies): Federal agency (or agencies) either preparing or taking primary responsibility for preparing the NEPA compliance documents.

Lee Ferry: Reference point marking division between the Upper and Lower Colorado River basins. The point is located in the mainstream of the Colorado River 1 mi below the mouth of the Paria River in Arizona.

Lees Ferry: The historic location of Colorado River ferry crossings (1873 to 1928) and the current site of the U.S. Geological Survey stream gage above the Paria River confluence.

Limnology: Scientific study of the physical, chemical, meteorological, and biological aspects of freshwater bodies.

Listed species: Species, subspecies, or distinct population segments that have been added to the federal list of endangered and threatened wildlife and plants and receive legal protection under the ESA.

Load: Amount of electrical power or energy delivered or required at a given point.

Load-following: A pattern of hydropower generation that reacts instantaneously to change in demand for power.

Loam: Soil consisting of an easily crumbled mixture of clay, silt, and sand.

Low flow: Flow releases from the dam at a rate of 8,000 cfs or less.

Lower Basin: Those parts of the states of Arizona, California, Nevada, New Mexico, and Utah, within and from which waters drain naturally into the Colorado River below Lee Ferry, Arizona; defined by the Colorado River Compact of 1922.

Lower Colorado River Multi-Species Conservation Plan (MSCP): 50-year multi-stakeholder federal and non-federal partnership set up to protect the lower Colorado River environment while ensuring the certainty of existing river water rights and power operations; address the needs of threatened and endangered native species and their habitats in compliance with state and federal endangered species laws; and reduce the likelihood of listing additional species along the lower Colorado River.

Lower Division: Division of the Colorado River system that includes the states of Arizona, Nevada, and California; area defined by Article II of the Colorado River Compact of 1922.

Lower-elevation balancing tier: Operation elevation that applies when Lake Powell’s projected January 1 elevation is below 3,525 ft (1,074 m) AMSL. The tier provides for attempting to balance the contents of Lake Mead and Lake Powell, if possible, within the constraint that the release from Lake Powell would be not more than 9.5 maf and no less than 7.0 maf.

M

Macroinvertebrate: Animal without vertebrae, usually with a hard exoskeleton or shell, of a size large enough to be seen by the unaided eye.

Macrophyte (aquatic): Aquatic plant that is large enough to be observed with the naked eye. Grows in or near water.

Main channel: Deepest or central part of the bed of a stream or river, containing the main current.

Mainstem: Main course of a stream or river.

Mainstream: Principal or largest stream or river of a given area or drainage basin; in this document, the Colorado River.

Major federal action: Proposed federal undertaking entirely or partly financed, assisted, conducted, regulated, or approved by federal agencies that has the potential for significant impacts on the human environment and is thus subject to federal control and responsibility.

Mammal: Air-breathing animal whose skin is more or less covered with hair or fur and has mammary glands. Young are born alive (except for the platypus and echidna) and are nourished with milk. Mammals include humans, dogs, cats, deer, mice, squirrels, raccoons, bats, opossums, whales, seals, and others.

Management action: Decision-making response carried out to achieve a specific purpose.

Meander: Bends and loops in a river channel as the river snakes through a flat land area.

Mechanical removal (fish): Use of electrofishing, nets, and other gear types to physically remove fish from an ecosystem. See *electrofishing*.

Median: Middle value in a distribution, above and below which lie an equal number of values.

Megawatt (MW): One million watts of electrical power.

Megawatt-hour (MWh): One million watt-hours of electrical energy.

Memorandum of Understanding (MOU): Document structuring the collaboration among federal agencies and other stakeholders (e.g., Tribes, local governments) and describing an intended common line of action.

Mesa: A broad, flat-topped elevation with one or more steeply sloping to vertical sides.

Mesozoic age: An era of geologic time between the Paleozoic and the Cenozoic eras, spanning the time between 251 and 65 million years ago. The word Mesozoic is from Greek and means "middle life."

Metalimnion: Middle layer of a thermally stratified lake or reservoir where there exists a rapid decrease in temperature with depth. Also called thermocline.

Meteorology: Study of the Earth’s atmosphere, particularly its patterns of climate and weather.

Metric ton: Unit of mass equal to 1,000 kilograms.

Microclimate: The climate of a small area, particularly that of the living space of a certain species, group, or community.

Mid-elevation tier: Operation elevation that applies when Lake Powell’s projected January 1 elevation is below 3,575 ft (1,090 m) AMSL and at or above 3,525 ft (1,074 m) AMSL. The annual releases in this tier are either 7.48 maf or 8.23 maf, depending upon the projected elevation of Lake Mead being above or below 1,025 ft (312 m) AMSL, respectively.

Midge: A very small, non-biting, two-winged insect, related to deer flies, mosquitos, and craneflies.

Mill: Monetary cost and billing unit used by utilities; equal to 1/1,000 of a U.S. dollar (equivalent to 1/10 of one cent).

Milligram per liter: Equivalent to one part per million.

Million acre-feet (maf): Unit of volume; the volume of water that would cover 1 million acres to a depth of 1 foot.

Mineral: Naturally occurring inorganic element or compound having an orderly internal structure and characteristic chemical composition, crystal morphology, and physical properties such as density and hardness. Minerals are the fundamental units from which most rocks are made.

Minimum flow: The lowest flow that occurs during the day, month, or year.

Mitigation: Action implemented to eliminate, avoid, minimize, or reduce the severity of an adverse impact on a particular resource resulting from the proposed action or its alternatives. Mitigation can include one or more of the following: (1) avoiding impacts; (2) minimizing impacts by limiting the degree or magnitude of an action; (3) rectifying impacts by restoration, rehabilitation, or repair of the affected environment; (4) reducing or eliminating impacts over time; and (5) compensating for the impact by replacing or providing substitute resources or environments to offset the loss.

Modified low fluctuating flow (MLFF): Current operating flow regime for the Glen Canyon Dam. The MLFF regime was established as the preferred alternative in the 1995 EIS and subsequent 1996 Record of Decision (ROD). In general, MLFF combines reduced daily flow fluctuations below the historic pattern of releases with high steady releases of short duration, intended to protect or enhance downstream resources while allowing limited flexibility for power operations. Established flows included minimum flows of no less than 8,000 cfs between 7 a.m. and 7 p.m., and 5,000 cfs at night; maximum rate of release limited to 25,000 cfs during fluctuating hourly releases; and releases of greater than 25,000 cfs (other than for emergencies) made steady on a daily basis in response to high inflow and storage conditions.

Monoculture: the cultivation or growth of a single crop or organism, especially on agricultural or forest land.

Monsoon: Rain event caused by a change in atmospheric circulation (e.g., wind direction) that results in stormy conditions, including excessive rainfall.

Morphology: Form and structure of an object (e.g., biological organism or rock formation) or any of its parts.

Mortality: Relative incidence or prevalence of death in a population.

Mouth (river): Natural opening, as the part of a stream or river, that empties into a larger body of water (e.g., another river, lake, bay, or ocean).

Myxozoa: Group of small parasitic animals that live in aquatic environments; one species in this group, *Myxobolus cerebralis*, is the parasite that causes whirling disease in rainbow trout.

N

National Ambient Air Quality Standards (NAAQS): Air quality standards established by the CAA, as amended. The primary NAAQS specify maximum outdoor air concentrations of criteria pollutants that would protect the public health within an adequate margin of safety. The secondary NAAQS specify maximum concentrations that would protect the public welfare from any known or anticipated adverse effects of a pollutant.

National Environmental Policy Act of 1969 (NEPA): Act passed by Congress in 1969 that sets national policy, procedures, tools, and compliance measures to support environmental protection, including encouraging productive harmony between people and their environment; promoting efforts that will prevent or eliminate damage to the environment and the biosphere and simulate the health and welfare of people; enriching the understanding of the ecological systems and natural resources important to the nation; and establishing a Council on Environmental Quality. It requires federal agencies to integrate environmental values into their decision-making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet this requirement, federal agencies prepare one of the following: a categorical exclusion, an EA, or an EIS.

National Historic Preservation Act (NHPA): Federal law providing that property resources with significant national historic value be placed on the *National Register of Historic Places*. It does not require permits; rather, it mandates consultation with the proper agencies whenever it is determined that a proposed action might affect a historic property.

National Register of Historic Places (NRHP): Official list of the nation's cultural resources worthy of preservation. Authorized under the NHPA, the NRHP is part of a national program to coordinate and support public and private efforts to identify, evaluate, and protect historic and archeological resources. Properties listed in the NRHP include districts, sites, buildings, structures, and objects that are significant in American history, architecture, archeology, engineering, and culture.

Native: Species of plants or wildlife that originated in the particular area or region in which they are growing or living.

Native American: See *American Indian*.

Native American Graves Protection and Repatriation Act (NAGPRA): Act that established the priority for ownership or control of Native American cultural items excavated or discovered on federal or Tribal land after 1990 and the procedures for repatriation of items in federal possession. The act allows for the intentional removal or excavation of Native American cultural items from federal or Tribal lands only with a permit or upon consultation with the appropriate Tribe.

Natural condition: State or status of resources that would occur (to the extent practicable) in the absence of human activities and/or dominance over the landscape.

Natural flow: The flow of any stream or river as it would be if unaltered by upstream diversion, storage, import, export, or change in upstream consumptive use caused by human activities.

Natural resource: Features and values that are inherently supplied by nature and considered to have value, including plants and animals, water, air, soils, topographic features, geologic features, and paleontological resources.

Natural Zone: An area managed for the conservation of natural resources and ecological processes while providing for their use by the public, as established by the National Park Service.

Nearshore: Area located between the boundary of the mainstem current and the shoreline. These regions are typically characterized by low water velocities (compared to the mainstem) and reduced turbulent mixing.

Nematode: An elongated, cylindrical worm parasitic in animals, insects, or plants, or free-living in soil or water.

Neotropical migratory bird: Bird that breeds in North America (i.e., Canada and the United States) during the spring and summer months and spends the winter months in Mexico, Central America, South America, or the Caribbean islands.

New High Water Zone (NHWZ): The area located next to the river, corresponding to river flows of 25,000 to 40,500 cfs, colonized with vegetation since the construction of Glen Canyon Dam; typically composed of riparian species, both native and nonnative.

Nitrate (NO_3): Naturally occurring plant nutrient that is essential to all life. It commonly enters water supply sources from decaying plants, manures, fertilizers, or other organic residues.

Nitrogen dioxide (NO_2): Toxic reddish brown gas that is a strong oxidizing agent, produced by combustion (as of fossil fuels). It is the most abundant of the oxides of nitrogen in the atmosphere and plays a major role in the formation of ozone. NO_2 is one of the six criteria air pollutants specified under Title I of the CAA. See *nitrogen oxides*.

Nitrogen oxides (NO_x): Includes various nitrogen compounds, primarily nitrogen dioxide and nitric oxide. They form when fossil fuels are burned at high temperatures and react with volatile organic compounds to form ozone, the main component of urban smog. They are also precursor pollutants that contribute to the formation of acid rain.

No action alternative: An alternative required by CEQ to be included in all EAs and EISs, representing conditions that would occur if the agency did not take the proposed action being considered. The environmental effects resulting from taking no action are compared to the effects of permitting the proposed action or any other action alternative to go forward.

Nonattainment area: The EPA’s designation for an air quality control region (or portion thereof) in which ambient air concentrations of one or more criteria pollutants exceed NAAQS.

Non-firm power: Power that is not available continuously and may be interruptible; may be marketed on a short-term basis.

Nonnative: Species of plants or wildlife that did not originate in the particular area in which they are growing or living and that often interfere with natural biological systems.

Non-use valuation: The process of assigning a non-use value to a resource.

Non-use value: The economic benefit that arises from the knowledge that a resource exists (existence value), has been preserved for potential use in the future (option value), and will be available for use by one’s heirs (bequest value). Non-use value is theoretically and conceptually distinct from use value. Contingent valuation is the only technique currently available for estimating non-use value.

Normal condition: As it relates to the Colorado River, when the Secretary of the Interior has determined that there is available water for annual releases totaling 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to Article II(B)(1) of the Consolidated Decree.

Notice of Intent (NOI): Announcement published in the *Federal Register* that an EIS will be prepared and considered. Includes description of the proposed action and alternatives; provides time, place, and descriptive details of the proposed scoping process; and identifies the lead agency (or agencies) contact person.

NPS-28, Cultural Resource Management Guidelines: National Park Service guidelines that elaborate on policies and standards and offer guidance in applying them to establish, maintain, and refine park cultural resource programs.

Nutrients: Chemical elements or compounds that are essential to plant and animal growth and development, such as nitrogen and phosphorus. Nutrients are measured in milligrams per liter (mg/L).

O

Obligate species: Restricted to a particular condition of life; for example, dependent on a particular habitat to be able to breed.

Off-peak energy: Electric energy supplied during periods of relatively low system demand.

Old High Water Zone (OHWZ): Area of vegetation above the level corresponding to flood flows of about 120,000 to 125,000 cfs; typically composed of native tree species.

On-peak energy: Electric energy supplied during periods of relatively high system demand.

Operating tier: Pursuant to the Interim Guidelines established in 2007, coordinated operations of Lake Powell and Lake Mead defined four operation tiers: (1) Equalization Tier, (2) Upper Elevation Balancing Tier, (3) Mid-Elevation Tier, and (4) Lower Elevation Balancing Tier. See specific tiers for additional information.

Organic matter: Material derived from living plant or animal organisms.

Organochlorine pesticide: Pesticide containing a compound of carbon, chlorine, and hydrogen that does not break down easily and is stored in fatty tissues of any animal ingesting it. Accumulates in animals in higher trophic levels.

Oscillatoria: Genus of benthic (bottom-dwelling) cyanobacteria or plankton (blue-green algae) occurring in blooms in fresh water.

Ostracod: Group of small crustaceans with a bivalved carapace that can be closed to completely cover the body; important planktonic fish food.

Outage (power): Period during which a generating unit, transmission line, or other facility is out of service and power is not available.

Outflow (hydrology): Amount or rate of water flowing out of or from a body of water. In this report it refers to water leaving Lake Powell by way of Glen Canyon Dam.

Outlet works: Device, usually consisting of one or more bypass pipes or tunnels through the embankment of the dam, used to release and regulate water flow from a dam. These structures are similar in purpose to spillways, but outlet works can provide a lower volume and more controlled release. See *jet tube*.

Ozone (O_3): Strong-smelling, reactive, toxic gas consisting of three oxygen atoms chemically attached to each other. Ozone is formed in the atmosphere by chemical reactions involving NO_x and volatile organic compounds (VOCs) in the presence of sunlight. Ozone is one of the six criteria air pollutants under the CAA and is a major constituent of smog.

P

Paleoclimate: a climate prevalent at a particular time in the geologic past.

Paleoindian period: A late Pleistocene stage of cultural evolution in the Americas at the end of the last ice age, when the first traces of human activity begin to appear in the archaeological record characterized by big-game hunting and the use of fluted projectile points.

Paleozoic: An era of geologic time, from the end of the Precambrian to the beginning of the Mesozoic, or from about 542 to 251 million years ago; also, the rocks deposited during this time.

Parasite: Organism that lives on or in an organism of another species (i.e., host) in a way that harms or is of no advantage to the host. Parasites rarely kill their hosts, instead, they obtain nutriment from the host body to live, grow, and multiply.

Particulate matter (PM): Fine solid or liquid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions that stick to lung tissue when inhaled. The size of the particulates is measured in micrometers (µm), which is 1 millionth of a meter (0.000039 in.). Particle size is important because the EPA has set standards for $PM_{2.5}$ and PM_{10} particulates, both of which are criteria air pollutants under the CAA. See $PM_{2.5}$ and PM_{10}.

Pathogen: Bacterium, virus, or other microorganism that can cause disease in other living microorganisms or in humans, animals, and plants.

Peak demand: See *peak load*.

Peak flow: Maximum instantaneous flow in a specified period of time.

Peak load: Maximum electrical demand in a stated period of time.

Peak load plant: Powerplant that normally is operated to provide power during maximum load periods.

Peaking power: Powerplant capacity typically used to meet the highest levels of demand in a utility's load or demand profile.

Penstock: Conduit pipe used to convey water under pressure from a storage reservoir to the turbines of a hydroelectric powerplant.

Per capita income: The average income per person in a given group.

Perennial stream: Stream that flows continuously throughout the year because it lies at or below the groundwater table, which constantly replenishes it.

Periphyton: Complex mixture of algae, cyanobacteria, other microbes, and detritus that is attached to submerged surfaces in most aquatic ecosystems. It serves as an important food source for invertebrates, tadpoles, and some fish.

pH: A measure of the relative acidity or alkalinity of a solution, expressed in a scale of 0 to 14, with a neutral point at 7. Acid solutions have pH values lower than 7, and basic (i.e., alkaline) solutions have pH values higher than 7.

Phantom Ranch: Constructed in 1922, the Phantom Ranch is the only accommodation for hikers in the inner Grand Canyon. It consists of a cluster of guest houses and a canteen lying between Bright Angel Creek and the Colorado River in GCNP.

Phosphorous: Essential chemical food element that can contribute to the eutrophication of lakes and other water bodies. Increased phosphorus levels result from discharge of phosphorus-containing materials into surface waters.

Photosynthesis: Process in which chlorophyll-containing cells convert light into chemical energy, forming organic compounds from inorganic compounds.

Phreatophyte: Any plant, typically living in the desert, that obtains its water from long taproots that reach the water table.

Physiography: The physical geography of an area or the description of its physical features.

Phytoplankton: Microscopic, single-celled photosynthetic organisms that live suspended in water.

Piscivorous: Habitually feeding on fish.

Plankton: Tiny plant (phytoplankton) and animal (zooplankton) organisms with limited powers of locomotion usually living free in the water away from substrates.

Plano technological complex: Distinctive early Paleoindian culture defined by a range of unfluted stone projectile points. Plano technology dates to 11,000 to 8,000 years ago.

PM_{10}: Particulate matter with a mean aerodynamic diameter of 10 µm (0.0004 in.) or less. Particles with diameters smaller than this can be inhaled and accumulate in the respiratory system. PM_{10} is one of the six criteria pollutants specified under Title I of the CAA.

$PM_{2.5}$: Particulate matter with a mean aerodynamic diameter of 2.5 µm (0.0001 in.) or less. Particles with diameters smaller than this can lodge deeply in the lungs. $PM_{2.5}$ is one of the six criteria pollutants specified under Title I of the CAA.

Pollinator: Agent, such as an insect or bird, that moves pollen from the male anthers of a flower to the female stigma of a flower to accomplish fertilization.

Pollutant: Any material entering the environment that has undesired effects.

Ponding flow: Relatively high flows that produce warm low-velocity slackwater areas at tributary mouths that provide thermal refuges for drifting larvae and young warmwater fish (e.g., humpback chub).

Pool: Deep area of a stream or river between rapids or where the current is slow.

Post-dam: Period of time after the completion of Glen Canyon Dam in 1963.

Power demand: Rate at which electric energy is required and delivered to or by a system over any designated period of time.

Power marketing: Process by which Western Area Power Administration sells power generated at Glen Canyon Dam and other Colorado River Storage Project facilities. Subject to a number of requirements established under statutory criteria.

Power operations: Physical operations of a large electrical power system, including hydropower generation, control (operational flexibility, scheduling, load following, and reserves), and transmission.

Power pool: Two or more interconnected electric systems that operate on a coordinated basis to achieve economy and reliability in supplying their combined loads.

Powerplant: Structure that houses turbines, generators, and associated control equipment related to the generation of electrical power.

Powerplant capacity: For Glen Canyon Dam, maximum flow that can pass through the turbines when Lake Powell is full (33,200 cfs). Also refers to the electrical capacity of the generators; total nameplate generating capacity for the powerplant is 1,021,248 kilowatts.

Pre-dam: Period of time before the completion of the Glen Canyon Dam in 1963.

Predation: Act of preying or plundering, specifically the interaction between species when one animal (predator) captures and eats another animal (prey).

Predatory: Relating to or characteristic of organisms that survive by preying on other organisms for food.

Preference customer: In accordance with congressional directives, publicly owned systems, and nonprofit cooperatives that have preference over investor-owned systems for purchase of power from federal projects.

Preferred alternative: Alternative the lead agency (or agencies) believes would fulfill its statutory mission and responsibilities under NEPA, giving consideration to economic, environmental, technical, and other factors.

Prescribed fires: Application of fire (by planned or unplanned ignitions) to fuels in either their natural or modified states, under specified conditions, to allow the fire to burn in a predetermined area while producing the fire behavior required to achieve certain management objectives.

Prevention of significant deterioration (PSD): A federal air pollution permitting program intended to ensure that air quality does not diminish in attainment areas that meet NAAQS.

Primitive: Belonging to or characteristic of an early age of development.

Productivity (ecology): Rate of biomass generation by an individual, population, or community within an ecosystem. Also, the fertility or capacity of a given habitat or area.

Programmatic Agreement (PA): Document that records the terms and conditions agreed upon to resolve the potential adverse effects of a federal agency program, complex undertaking, or other situations in accordance with Section 800.14(b), “Programmatic Agreements,” of 36 CFR Part 800, “Protection of Historic Properties.”

Project area: Area in which a proposed action would occur and directly affect the environment. The project area for the LTEMP EIS is Lake Powell, Lake Mead, and the Colorado River and its corridor in between.

Proliferation: Rapid growth or increase in production of new parts or offspring.

Proposed action: An action proposed by an agency, subject to a NEPA analysis.

Proterozoic era: Final era of the Precambrian, spanning the time between 2.5 billion and 544 million years ago. Fossils of both primitive single-celled and more advanced multicellular organisms begin to appear in abundance in rocks from this era. Its name means “early life.”

Protohistoric: Period between prehistory and history, during which a culture or civilization has not yet developed writing but other cultures have already noted its existence in their own writings. The protohistoric culture may also be in the process of developing its own writing techniques and creating its own written record.

Public involvement: Process of obtaining public input into each stage of development of planning documents. Required as a major input into any EIS.

R

Radionuclide: Unstable nuclide that undergoes radioactive decay.

Ramp rate: Rate of change (cfs/hr) in instantaneous dam releases. The ramp rate is established to prevent undesirable effects due to rapid changes in loading or, in the case of hydroelectric powerplants, discharge.

Range: Geographic region in which a given plant or animal normally lives or grows.

Rapid: Turbulent section of a river. Fast-flowing current typically is caused by a relatively steep descent in the riverbed or a constriction of the main channel.

Reach: Any specified length of a stream or river.

Rearing: Bringing up from the early stages of life, through maturity, until fully grown.

Reattachment bar: Sandbar located where downstream flow meets the riverbank at the downstream end of a recirculation zone. An element of a fan-eddy complex.

Recirculation zone: Area of flow composed of one or more eddies immediately downstream from a constriction in the channel, such as a debris fan or rock outcrop. An element of a fan-eddy complex.

Reclamation Project Act of 1939: This act provides a comprehensive plan for the variable payment of construction charges on U.S. reclamation projects.

Record of Decision (ROD): Document separate from but associated with an EIS that publicly and officially discloses the responsible agency's decision on the EIS alternative to be implemented.

Recovery: Return to or regaining of any former and better state or condition. As it relates to ESA, recovery is the process by which the decline of an endangered or threatened species is arrested or reversed, and threats to its survival (including the ecosystem upon which they depend) are neutralized, so that its long-term survival in nature can be ensured.

Recruitment: Survival of young plants and animals from birth to reproductive age or a life stage less vulnerable to environmental change.

Redd: Depression, or spawning nest, dug by fish (especially trout or salmon) in river- or lakebed for the deposition of eggs.

Redeposition: Formation into a new accumulation, such as the settlement of sedimentary material that has been picked up and moved (reworked) from the place of its original deposition.

Refuge: Protection or shelter, as from something dangerous, threatening, harmful, or unpleasant.

Refugia: Locations or areas where conditions remain suitable to allow a species or a community of species to survive following extinction in surrounding areas. Plural of refugium.

Region of influence (ROI): Area occupied by affected resources and the distances at which impacts associated with a proposed action may occur.

Regulation: Capacity devoted to providing the minute-by-minute change in generation above and below a generator's operating set point. It is needed to maintain a constant voltage within a power control area given variation in generator units. Regulation results in instantaneous deviations above and below the mean hourly flow within each hour that do not affect the mean hourly flow over a full hour. In the United States, regulating capacity is controlled by computers (via automatic generation control).

Reptile: Cold-blooded vertebrate of the class Reptilia whose skin is usually covered in scales or scutes. Reptiles include snakes, lizards, turtles, crocodiles, and alligators.

Reserve generating capacity: Extra generating capacity available to meet unanticipated capacity demand for power in the event of generation loss due to scheduled or unscheduled outages of regularly used generating capacity.

Reservoir: Natural or artificially impounded body of water, commonly created by the building of a dam, that is used for the storage, regulation, and control of water.

Reservoir capacity: Total or gross storage capacity of the reservoir at full supply level.

Restoration: Manipulation of the physical, chemical, or biological characteristics of a resource or site with the goal of improving or returning its natural/historic functions to any former and better state or condition.

Return-current channel: Channel excavated by upstream eddy flow that forms behind a reattachment bar. See *backwater*.

Riffle: Stretch of choppy water caused by an underlying rock shoal or sandbar.

Riparian: Along a river, pond, lake, or tidewater.

Riparian zone: Area encompassing the alluvial sediment deposits where river and alluvial groundwater supplement that available from local precipitation.

Risk: Likelihood of suffering a detrimental effect as a result of exposure to a hazard.

River basin: Land area surrounding one river from its headwaters to its mouth. The area drained by a river and its tributaries.

River corridor: River and the area of land adjacent to it, including the talus slopes at the bases of cliffs, but not the cliffs themselves.

River mile (RM): Unit of measurement (in miles) that quantifies distance (or length) in miles along a river from its mouth or other reference point. On the Colorado River, River Mile 0 is located at the U.S. Geological Survey gage at Lees Ferry, Arizona; points downstream are positive values while those upstream are negative.

River runner: Individual who recreationally navigates a moving body of water, typically a whitewater river, using a raft, kayak, or other type of boat. See *whitewater rafting*.

River stage: Water surface elevation of a river above a reference datum.

Riverine: Of, resembling, relating to, or situated on a river or riverbank.

RiverWare: Commercial river system simulation computer program that was configured to simulate operation of the Colorado River for this EIS.

Rotifer: Microscopic, multicellular invertebrates from the class Rotifera; common in freshwater.

Runoff: Portion of the precipitation, melted snow, or irrigation water that flows across ground surface and eventually is returned to surface water sources. Runoff can pick up pollutants from the air or land and carry them to the receiving waters.

S

Sacred landscape: Natural places recognized by a cultural group as having spiritual or religious significance.

Sacred site: Any specific, discrete, narrowly delineated location on federal land that is identified by an Indian Tribe, or Indian individual determined to be an appropriately authoritative representative of an Indian religion, as sacred by virtue of its established religious significance to, or ceremonial use by, an Indian religion; provided that the Tribe or appropriate authoritative representative of an Indian religion has informed the agency of the existence of such a site.

Salinity: Degree of dissolved minerals (e.g., salts) in water. Also commonly referred to as total dissolved solids (TDS). See *total dissolved solids*.

Salmonid: Of, belonging to, or characteristic of fish belonging to the Salmonidae family, which includes salmon, trout, and whitefish.

Salt Lake City Area Integrated Projects (SLCA/IP): Part of an interconnected generation and transmission system that includes federal, public, and private power-generating facilities.

Sand: Rock or mineral fragment of any composition that has a diameter ranging from 0.5 to 2.0 mm. Sand has a gritty feel.

Sand budget: Management tool used to analyze and describe the various sand and sediment inputs (sources) and outputs (sinks) within a defined system; can be used to predict morphological change over time.

Sand load: See *sediment load*.

Sand mass balance: Difference between the mass of sand being transported into an area and the mass of sand being transported out of the area. A positive sand mass balance indicates that sand is accumulating in the area, whereas a negative sand mass balance indicates that the mass of sand is decreasing in the area.

Sandbar: Any of the fine-grained alluvial deposits that intermittently form the riverbank. These fine-grained deposits are in contrast to the rocky surfaces predominately found throughout the Grand Canyon. See *beach*.

Sandstone: Sedimentary rock composed primarily of sand-sized (0.0025 to 0.08 in.) grains.

Scheduled outage: Shutdown of a generating unit or other facility for inspection or maintenance, in accordance with an advance schedule.

Scheduling: Matching of daily system energy and capacity needs with available generation.

Schist: Metamorphic rock formed from many types of rocks. Minerals in the rocks include micas, chlorite, talc, hornblende, and garnets. The minerals are characteristically platey and foliated (layered), indicating they were subjected to intense compression.

Scope: Range of actions, alternatives (including no action), and impacts to be considered in an EIS.

Scoping: Process required by NEPA to solicit input, issues, and information from within the agency, other agencies, and the public related to the proposed action prior to preparation of an EIS. Scoping assists the preparers of an EIS in defining the proposed action, identifying alternatives, and developing preliminary issues to be addressed in an EIS.

Scour: Erosion in or along a stream bed caused by high flow velocities.

Secretary: Secretary of the Department of the Interior (DOI) and duly appointed successors, representatives, and others with properly delegated authority.

Sediment: Unconsolidated solid material that is washed from land (e.g., from weathering of rock) and is carried by, suspended in, or deposited by water or wind. Sediment varies in size and includes clay, silt, sand, gravel, and cobble.

Sediment augmentation: Adding sand-, silt-, or clay-size sediments to the Colorado River to increase turbidity or sediment supply.

Sediment load: Mass of sediment passing through a stream cross-section in a specified period of time.

Sediment transport: Movement of sediment in a downstream direction caused by flowing water.

Sedimentary rock: Rock formed at or near the Earth's surface from the consolidation of loose sediment that has accumulated in layers through deposition by water, wind, or ice, or organisms. Examples are sandstone and limestone.

Sedimentation: Removal, transport, and deposition of sediment particles by wind or water.

Seep: Moist or wet place where groundwater slowly exits through soil or rock.

Seepage: Relatively slow movement of water through a medium such as sand.

Semi-arid: Moderately dry region or climate where moisture is normally greater than under arid conditions but still limits the production of vegetation.

Sensitive species: Plant or animal species listed by the state or federal government as threatened, endangered, or a species of special concern. The list of sensitive species typically varies from state to state, and the same species can be considered sensitive in one state but not in another. Also, a species that is adversely affected by disturbance or altered environmental conditions. See also *special status species*.

Separation bar: Sandbar located at the upstream end of a recirculation zone, where downstream flow becomes separated from the riverbank, creating an eddy.

Shoal: Shallow area in a body of water.

Shortage condition: When the Secretary has determined that there is available for annual release less than 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to Article II(B)(3) of the Consolidated Decree.

Silt: Fine rock fragments or mineral particles of any composition between sand and clay in size that have diameters ranging from 0.002 to 0.05 mm.

Simulid: Group of two-winged flying insects who live their larval stage underwater and emerge to fly about as adults.

Sinuous: Ratio of the length of a river's thalweg to the length of the valley proper. A measure of a river's meandering.

Site: In archeology, any location of past human activity.

Slope: Change in elevation per unit of horizontal distance.

Socioeconomic: Social and economic conditions in the study area.

Solar radiation: Electromagnetic radiation emitted by the sun.

Soundscapes: Sound or combination of sounds that forms or arises from an immersive environment.

Spawn: To lay eggs, especially fish.

Spawning beds: Places where eggs of aquatic animals lodge or are placed during or after fertilization.

Special status species: Any plant or animal species that is listed or proposed for listing as threatened or endangered by the FWS or NMFS under the provisions of the ESA. Also any species designated by the FWS as “candidate,” “sensitive,” or a “species of concern”; or a species listed by a state in a category implying potential endangerment or extinction (e.g., sensitive or rare).

Species of special concern: Species that may have a declining population, a limited occurrence, or low numbers for any of a variety of reasons.

Spike flow: Natural or experimental increase in the flow of water for a short duration.

Spills: Water releases from Glen Canyon Dam that do not pass through the turbines for the generation of electricity.

Spillway: Overflow channel of a dam to provide a controlled release.

Spinning reserves: Extra generating capacity that is available for immediate use in response to system problems or sudden load changes by increasing the power output of generators that are already connected to the power system. Within minutes or less, reserves allow for increases in the water release rates at Glen Canyon Dam to increase power generation, up to a limit known as the spinning reserve requirement, to compensate for the loss in generation elsewhere in the grid.

Spring: Point at which groundwater meets the Earth’s surface, causing water to flow from the ground.

Stage: See *water-surface elevation*.

Stakeholder: Person, group, or organization that has direct or indirect investment, share, or interest in an organization or project because it can affect or be affected by related actions, objectives, and/or policies.

State Historic Preservation Office(r) (SHPO): The state officer charged with the identification and protection of prehistoric and historic resources in accordance with the NHPA.

Steady flow: Flow released from the dam at any volume that does not vary beyond a small percentage over a 24-hour period.

Stewardship: Conducting, supervising, managing, or protecting something considered of value or worth caring for and preserving. The concept of stewardship has been applied in diverse areas, including the environment, economics, health, property, information, and religion.

Strata: Single, distinct layers of sediment or sedimentary rock.

Stratification: Thermal layering of water in lakes and streams. Lakes usually have three zones of varying temperature: epilimnion—top layer with essentially uniform warmer temperature; metalimnion—middle layer of rapid temperature decrease with depth; and hypolimnion—bottom layer with essentially uniform colder temperatures.

Stratigraphy: Layers of sediments and rocks that reflect the geologic history of an area. With respect to cultural resources and archaeological sites, the relative stratigraphic locations of human artifacts help determine the sequence in which past human activities took place.

Stream: Natural water course. See *ephemeral stream*, *intermittent stream*, and *perennial stream*.

Stream flow: Volume or rate, expressed in cubic feet per second (cfs), of water moving in a stream or river, at any given time.

Stream gage: Active, continuously functioning field measuring device for which stream flow is computed or estimated.

Subadult: Fish that are less than 3 years of age.

Subsistence: The practices by which a group or individual acquires food, such as through hunting and gathering, fishing, and agriculture.

Substrate: Surface on which a plant or animal grows or is attached.

Sulfur dioxide (SO_2): Colorless gas released from many sources, especially burning fossil fuels. Sulfur dioxide is one of the six criteria air pollutants specified under Title I of the CAA.

Sulfur oxides (SO_x): Compounds containing sulfur and oxygen, such as sulfur dioxide (SO_2) and sulfur trioxide (SO_3). Pungent, colorless gases that are formed primarily by fossil fuel combustion, notably from coal-fired powerplants. Sulfur oxides may damage the respiratory tract, as well as plants and trees.

Surface water: Water on the Earth's surface that is directly exposed to the atmosphere, as distinguished from water in the ground (groundwater).

Surplus condition: When the Secretary has determined that there is available for annual release more than 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to Article II(B)(2) of the Consolidated Decree.

Surplus energy: Energy greater than that of contracted firm load that may be available for a short-term period to serve additional load; usually attributed to favorable, but unanticipated, hydrologic conditions.

Suspended solids: Small particles of sand, silt, clay, and organic material moving with the water or along the bed of the stream that are not in true solution (i.e., can be removed by filtration or settling).

Suspension: Heterogeneous mixture of fine solid particles in a liquid or gas, such as sand in water. The suspended particles will settle over time, if left undisturbed, or can be removable by filtration.

Sustainable hydropower (SHP): Fixed level of long-term capacity and energy available from SLCA/IP facilities during summer and winter seasons; this amount is the minimum commitment level for capacity that Western will provide to all SLCA/IP customers.

Sweat lodge: In Native American culture, a ceremonial event of traditional prayers and songs that are held in a lodge constructed of a wood frame covered with blankets, with hot stones that release steam when water is poured on them.

T

Tailwater: Reach of river immediately downstream of a dam, where the water is more similar to that in the reservoir than farther downstream.

Talus: Sloping accumulation of rock debris; also, rock fragments at the base of a cliff as the result of sliding or falling.

Taxa: Taxonomic unit or category within the biological system of classification to which organisms are assigned, including species, genus, family, order, class, and phylum.

Technical Work Group (TWG): Subcommittee comprised of technical representatives of the Adaptive Management Work Group (AMWG) to develop criteria and standards for monitoring and research programs.

Temperate: Moderate climate that lacks extremes in temperature.

Temperature control device (TCD): Apparatus used to modify the dam’s penstocks to allow for selective withdrawal from the reservoir, as to influence the temperature of the release water (e.g., warm surface water versus cold deep water).

Temporal: Of, relating to, or limited by time.

Temporary structure: Any structure that can be readily and completely dismantled and removed from the site between periods of actual use. It may or may not be authorized at the same site from season to season or from year to year.

Terrace: Surface form of a high sediment deposit having a relatively flat surface and steep slope facing the river.

Terrain: Topographic layout and features of a tract of land or ground.

Terrestrial: Pertaining to plants or animals living on land rather than in water.

Texture: Visual manifestations of light and shadow created by the variations in the surface of an object or landscape.

Thalweg: Line connecting the deepest points along the length of a valley or riverbed.

Thermal: Of, relating to, affected by, or producing heat.

Thermocline: Zone of maximum change in temperature in a water body, separating upper (epilimnetic) from lower (hypolimnetic) zones.

Threatened species: Any species or subspecies that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Requirements for declaring a species threatened are contained in the ESA of 1973.

Toe: Point at which the bottom of a slope or embankment intersects the natural ground, such as the upstream or downstream toe of the dam or the downstream toe of a landslide or debris fan.

Topography: Physical shape of the ground surface; the relative position and elevations of natural and human-made features of an area.

Total dissolved solids (TDS): Dissolved materials in the water including ions such as potassium, sodium, chloride, carbonate, sulfate, calcium, and magnesium. In many instances, the term TDS is used to reflect salinity, since these ions are typically in the form of salts. See *salinity*.

Toxicity: Harmful effects on an organism caused by exposure to a hazardous substance. Environmental exposures are primarily through inhalation, ingestion, or contact with the skin.

Trace (hydrology): Sequence of flows over a specified period of time.

Traditional Cultural Property (TCP): Site or resource that is eligible for inclusion in the NRHP because of its association with cultural practices or beliefs of a living community that are (1) rooted in that community's history, and (2) important in maintaining the continuing cultural identity of the community.

Traditional use area: Broad landscapes over which contemporary people and their ancestors have hunted, fished, and gathered.

Translocation: Intentional capture, movement, and release of individuals of a species from one location or area to another. This type of transfer is typically done to prevent harm to the individuals or to establish additional populations elsewhere.

Transmission line: Facility for transmitting electrical energy at high voltage from one point to another point.

Travertine: Sedimentary rock formed by the precipitation of carbonate minerals from solution in ground and surface waters, and/or geothermal hot springs.

Tribal land: In the NAGPRA, tribal land is defined as: (1) all lands within the exterior boundaries of any Indian reservation; (2) all dependent Indian communities; and (3) any lands administered for the benefit of Native Hawaiians pursuant to the Hawaiian Homes Commission Act, 1920, and section 4 of Public Law 86-3. In the NHPA, Tribal land is defined as (1) all lands within the exterior boundaries of any Indian reservation, and (2) all dependent Indian communities.

Tribe: Term used to designate a federally recognized group of American Indians and their governing body. Tribes may be comprised of more than one band.

Tributary: River or stream that flows into another stream, river, or lake.

Trigger: Condition-dependent or environmental cues that determine management actions.

Trophic: Of, relating to, or pertaining to nutrition, food, or feeding. For example, the feeding habits or food relationship of different organisms in a food chain.

Trout: Prized game fish native to the Northern Hemisphere, that has been widely introduced (i.e., it is nonnative) across the globe, including the Colorado River below Glen Canyon Dam (with exception of the native cutthroat trout). These fishes feature a streamlined, speckled body with small scales and soft fins, although their individual coloring and appearance can change depending on the specific surroundings and environment in which they live. Typically smaller than the related salmon, trout are usually found in cool (50–60°F, 10–16°C), clear freshwater streams and lakes. Trout are an important food source for humans and wildlife including brown bears, birds of prey (e.g., eagles), and other animals. However, their existence threatens many native fish species and their habitats owing to competition, displacement, and predation.

Trout management flow (TMF): Special type of fluctuating flow designed to reduce the recruitment of trout by disadvantaging young-of-the-year (YOY) trout.

Turbidity: Measure of the water clarity or the ability of light to pass through water. Affected by the amount of suspended particles, dissolved solids, and colloidal materials that are suspended in water.

Turbine: Device or machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, hot gas, or wind). Turbines convert the kinetic energy of fluids to mechanical energy through the principles of impulse and reaction, or a mixture of the two. Turbines are considered the most economical means of turning large electrical generators.

Turbulent: Marked or characterized by disturbances, changes, and unrest, such as unsteady motion and agitation of water.

U

Upper Basin: Those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming, within and from which waters drain naturally into the Colorado River above Lee Ferry, Arizona; defined by the Colorado River Compact of 1922.

Upper Colorado River Commission: Commission established by the Upper Colorado River Basin Compact with five appointed members, one from each of the Upper Division States (Colorado, New Mexico, Utah, Wyoming) and one representing the United States of America. Its purpose is to administer the Upper Colorado River Basin Compact.

Upper Division: Division of the Colorado River system that includes the states of Colorado, New Mexico, Utah, and Wyoming; area defined by Article II of the Colorado River Compact of 1922.

Upper-elevation balancing tier: Operation elevation that applies when Lake Powell's projected January 1 elevation is below the elevation in the equalization table of the Interim Guidelines, but above 3,575 ft (1,090 m) AMSL. The tier defines several different operations for attempting to balance the contents of Lake Mead and Lake Powell, if possible, that may occur based on the projected elevations of each lake, within the constraint that the release from Lake Powell would be not more than 9.0 maf and no less than 7.0 maf.

Upstream: Toward the source of a stream or river, against the normal direction of water flow.

Use value: Economic benefit associated with the physical use of a resource, usually measured by the consumer surplus or net economic value associated with such use. The contingent value method is one technique used to estimate use value.

V

Varial zone: Portion of the river bottom that is alternately flooded and dewatered.

Velocity: Rate of flow of water or water-sediment mixture.

Vertebrate: Animal species with a backbone. Includes fish, amphibians, reptiles, birds, and mammals.

Visibility degradation: Scattering and absorption of light by fine particles with a secondary contribution by gases; cumulative emissions of air pollutants from a myriad of sources.

Visitor day: Use of a site or area for 12 visitor hours, which may be aggregated by one or more persons for a single continuous or intermittent use (e.g., multiple visits).

Visitor use: Usage of recreation and wilderness resources by people for inspiration, stimulation, solitude, relaxation, education, pleasure, or satisfaction.

Visual contrast: Opposition or unlikeness of different forms, lines, colors, or textures in a landscape.

Visual impact: Any modification in land forms, water bodies, or vegetation, or any introduction of structures that negatively or positively affect the visual character or quality of a landscape through the introduction of visual contrasts in the basic elements of form, line, color, and texture.

Visual resource: Refers to all objects (manmade and natural, moving and stationary) and features such as landforms and water bodies that are visible on a landscape.

Volatile organic compound (VOC): Broad range of organic compounds that readily evaporate at normal temperatures and pressures. Sources include certain solvents (e.g., acetone), degreasers (e.g., benzene), and fuels (e.g., gasoline). VOCs also react with other substances (primarily nitrogen oxides) to form ozone. They contribute significantly to photochemical smog production and certain health problems.

W

Warmwater fish: Species of fish that grow best in water at least 80°F (27°). Warm water holds less DO than cool or cold water, so warmwater species, such as largemouth bass, catfish, and bluegill, require less oxygen to survive.

Wash: Normally dry streambed that occasionally conveys flowing water.

Water column: Hypothetical “cylinder” of water from the surface of a water body to the bottom, within which physical and chemical properties can be measured.

Water quality: Term used to describe the chemical, physical, and biological characteristics of water, usually with respect to its suitability for a particular purpose.

Water right: Legal entitlement of an individual or entity to extract water from a water source (surface water or groundwater) for a beneficial use (e.g., potable water supply, irrigation, mining, livestock).

Water table: Upper level of groundwater below which soil and rock are saturated with water.

Water year: Period of time beginning October 1 of one year and ending September 30 of the following year and designated by the calendar year in which it ends.

Waterfowl: Water birds, usually referring to ducks, geese, and swans.

Watershed: Region or area from which all water entering a particular water body drains. Also known as a basin.

Water-surface elevation (stage): Height, or elevation, of a water surface above or below an established reference level, such as sea level.

Weed: Plant considered undesirable, unattractive, or troublesome, usually introduced and growing without intentional cultivation.

Western Area Power Administration (WAPA): One of four power marketing administrations of the U.S. Department of Energy that markets and delivers reliable, renewable, cost-based hydroelectric power and related services within a 15-state region of the central and western United States.

Western Electricity Coordinating Council (WECC): Regional entity responsible for coordinating and promoting bulk electric system reliability in the Western Interconnection.

Wetlands: Federally protected areas that are saturated or flooded by surface or groundwater frequently enough or long enough to support plants, birds, and animals adapted to live in wet environments. Generally include swamps, marshes, bogs, estuaries, wet meadows, river overflows, mud flats, natural ponds, and other inland and coastal areas.

Wheeling: Occurs when two indirectly connected utilities agree to purchase or sell power to each other.

Whirling disease: Disease caused by a parasite; results in neurological damage to young fish, causing them to swim in a corkscrew pattern. Affected fish are unable to feed properly and are vulnerable to predators.

Whirlpool: Water moving rapidly in a circle so as to produce a depression.

Whitewater boating: See *whitewater rafting*.

Whitewater rafting: Recreational navigation of a moving body of water (e.g., river) characterized by fast-flowing rough water or rapids, using a raft, kayak, or other type of boat.

Wild and Scenic Rivers Act: Primary river conservation law enacted in 1968. The Act was specifically intended by Congress to balance the existing policy of building dams on rivers for water supply, power, and other benefits with a new policy of protecting the free-flowing character and outstanding values of other rivers.

Wilderness: Undeveloped land retaining its primeval character without permanent improvements or human habitation, and that generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable.

Wilderness Act of 1964: Legislation enacted in 1964 to designate wilderness areas, with Congressional approval, to ensure that these lands are preserved and protected in their natural condition.

Wilderness areas: Areas and lands designated by Congress and defined by the Wilderness Act of 1964 as places "where the earth and its community are untrammeled by man, where man himself is a visitor who does not remain." Designation is aimed at ensuring that these lands are preserved and protected in their natural condition.

Wilderness characteristics: Wilderness characteristics include (1) naturalness: the area generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) outstanding opportunities: the area has either outstanding opportunities for solitude, or outstanding opportunities for primitive and unconfined types of recreation; (3) size: the area is at least 5,000 acres (20 km^2) of land, or is of sufficient size to make practicable its preservation and use in an unimpaired condition; and (4) values: the area may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value.

Willingness to pay: Method of estimating the value of activities, services, or other goods, where value is defined as the maximum amount a consumer would be willing to pay for the opportunity rather than do without. The total willingness to pay, minus the user's costs of participating in the opportunity, defines the consumer surplus and benefits.

Wind rose: Circular diagram, for a given locality or area, showing the frequency and strength of the wind from various directions over a specified period of record.

World Heritage Site: Area identified by the World Heritage Committee of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) as having outstanding universal value for cultural and natural heritage.

X

Xeric: Low in moisture. Dry environmental conditions. Habitats or sites characterized by their limited water availability.

Y

Young-of-year (YOY): Young (usually fish) produced in the current calendar year. Also referred to as age 0.

Z

Zooplankton: Small, usually microscopic animals (such as protozoans), found in lakes and reservoirs. Zooplankton can be permanent (i.e., rotifers or cladocerans) or temporary, as with the early life stages (i.e., eggs, larvae, juveniles, and adults) of many fish and invertebrate species.