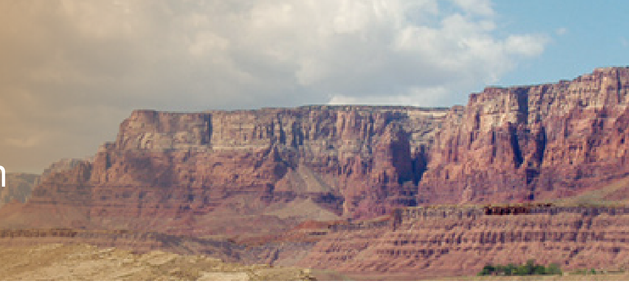
Glen Canyon Dam

Long-Term Experimental and Management Plan
Environmental Impact Statement



FINAL

Executive Summary

U.S. Department of the Interior
Bureau of Reclamation,
Upper Colorado Region
National Park Service,
Intermountain Region

October 2016

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CONTENTS

ACRONYMS AND ABBREVIATIONS ..... ES-vii

EXECUTIVE SUMMARY ES-1

ES.1 Introduction ES-1
ES.2 Proposed Federal Action ES-2
ES.2.1 Purpose of and Need for Action ES-3
ES.2.2 Objectives and Resource Goals of the LTEMP ES-3
ES.3 Scope of the EIS ES-6
ES.3.1 Affected Region and Resources ES-6
ES.3.2 Impact Topics Selected for Detailed Analysis ES-6
ES.4 Laws and Regulations Related to Operations of Glen Canyon Dam and Park Management ES-8
ES.4.1 Environmental Laws and Executive Orders ES-9
ES.4.2 Cultural/Historical Laws and Executive Orders ES-10
ES.4.3 American Indian and Tribal Consultation Laws and Executive Orders ES-10
ES.4.4 Laws Establishing Criteria Related to Power Marketing ES-10
ES.4.5 Law of the River ES-11
ES.5 Related Actions ES-11
ES.5.1 Biological Opinions ES-11
ES.5.2 Environmental Impact Statements and Related Documents ES-11
ES.5.2.1 Operation of Glen Canyon Dam: Environmental Impact Statement and Record of Decision ES-11
ES.5.2.2 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead ES-12
ES.5.2.3 Colorado River Management Plan: Final Environmental Impact Statement and Record of Decision ES-13
ES.5.2.4 Lower Colorado River Multi-Species Conservation Program—Final Programmatic Environmental Impact Statement/Environmental Impact Report ES-13
ES.5.2.5 General Management Plan for Grand Canyon National Park ES-13
ES.5.2.6 Backcountry Management Plan, Grand Canyon National Park, Arizona ES-13
ES.5.2.7 Lake Mead National Recreation Area General Management Plan—Final Environmental Impact Statement ES-14
ES.5.2.8 Glen Canyon National Recreation Area General Management Plan—Final Environmental Impact Statement ES-14

CONTENTS (Cont.)

ES.5.3 Environmental Assessments and Related Documents ES-14
ES.5.3.1 Nonnative Fish Control Environmental Assessment......... ES-14
ES.5.3.2 High-Flow Experiment Protocol Environmental Assessment ES-14
ES.5.3.3 Environmental Assessment, Comprehensive Fisheries Management Plan for Grand Canyon National Park and Glen Canyon National Recreation Area ES-15
ES.5.3.4 Environmental Assessment and Assessment of Effect, Exotic Plant Management Plan Grand Canyon National Park, Arizona ES-15
ES.5.4 Other Actions, Programs, Plans, and Projects ES-15
ES.5.4.1 Colorado River Basin Salinity Control Program............... ES-15
ES.5.4.2 Lake Powell Pipeline Project ES-15
ES.5.4.3 Final Wilderness Recommendation, Grand Canyon National Park, 2010 Update ES-16
ES.5.4.4 Grand Canyon National Park Foundation Statement for Planning and Management ES-16
ES.5.4.5 Glen Canyon National Recreation Area and Rainbow Bridge National Monument Foundation Document for Management and Planning ES-16
ES.5.4.6 Management and Control of Tamarisk and Other Invasive Vegetation at Backcountry Seeps, Springs, and Tributaries in Grand Canyon National Park ES-16
ES.5.4.7 Strategic Plan for Glen Canyon National Recreation Area and Rainbow Bridge National Monument FY2007–FY2011 .... ES-17
ES.5.4.8 Grand Canyon National Park Resource Management Plan ES-17
ES.6 Public Involvement... ES-17
ES.7 Descriptions of Alternatives ES-18
ES.7.1 Development of Alternatives... ES-18
ES.7.2 Descriptions of Alternatives Analyzed in the EIS ES-19
ES.7.2.1 Alternative A (No Action Alternative)............................ ES-23
ES.7.2.2 Alternative B ES-32
ES.7.2.3 Alternative C ES-32
ES.7.2.4 Alternative D (Preferred Alternative).............................. ES-33
ES.7.2.5 Alternative E.. ES-34
ES.7.2.6 Alternative F ES-35
ES.7.2.7 Alternative G ES-35
ES.8 Implementation of the LTEMP ES-36
ES.8.1 Operational Flexibility ES-36
ES.8.2 Experimental Implementation Process ES-37
ES.8.3 Descriptions of Potential Experiments ES-39

CONTENTS (Cont.)

ES.8.3.1 Sediment-Related Experiments ES-39
ES.8.3.2 Aquatic Resource-Related Experiments............................ ES-40
ES.8.3.3 Experimental Vegetation Treatment ES-41
ES.8.3.4 Hydropower Improvement Flows ES-41
ES.9 Affected Environment ES-42
ES.10 Environmental Consequences ES-44
ES.11 Unavoidable Adverse Impacts... ES-62
ES.12 Relationship between Short-Term Use and Long-Term Productivity................ ES-63
ES.13 Irreversible and Irretrievable Commitments of Resources................................ ES-63
ES.14 References ES-64

FIGURES

ES-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands................................... ES-7

ES-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output ES-45

TABLES

ES-1 Operational Characteristics of LTEMP Alternatives ES-24

ES-2 Condition-Dependent and Experimental Elements of LTEMP Alternatives ES-26

ES-3 Summary of Impacts of LTEMP Alternatives on Resources ES-47

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ACRONYMS AND ABBREVIATIONS

ac	acre(s)
ac-ft	acre-foot (feet)
AMWG	Adaptive Management Work Group
AZGFD	Arizona Game and Fish Department
BIA	Bureau of Indian Affairs
CFMP	Comprehensive Fisheries Management Plan
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
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
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EA	Environmental Assessment
EIS	Environmental Impact Statement
E.O.	Executive Order
ESA	Endangered Species Act of 1973
FONSI	Finding of No Significant Impact
ft	foot (feet)
FWS	U.S. Fish and Wildlife Service
GCDAMP	Glen Canyon Dam Adaptive Management Program
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
HFE	high-flow experiment
hr	hour(s)
in.	inch(es)
kaf	thousand acre-feet

LMNRA	Lake Mead National Recreation Area
LROC	Long-Range Operating Criteria
LTEMP	Glen Canyon Dam Long-Term Experimental and Management Plan
maf	million acre-feet
mi	mile(s)
mi^2	square mile(s)
MLFF	Modified Low Fluctuating Flow
MW	megawatt(s)
NEPA	National Environmental Policy Act of 1969, as amended
NM	national monument
NOI	Notice of Intent
NO_x	nitrogen oxides
NPS	National Park Service
NRHP	*National Register of Historic Places*
P.L.	Public Law
Reclamation	Bureau of Reclamation
ROD	Record of Decision
Secretary, the	Secretary of the Interior
SLCA/IP	Salt Lake City Integrated Projects
SO_2	sulfur dioxide
Stat.	Statute
TWG	Technical Work Group
UCRC	Upper Colorado River Commission
USC	*United States Code*
USGS	U.S. Geological Survey
WAPA	Western Area Power Administration

EXECUTIVE SUMMARY

ES.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.

The LTEMP Environmental Impact Statement (EIS) has been prepared to identify the potential environmental effects of implementing the proposed federal action. In addition, the 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. These alternatives include a broad range of operations and actions that would accomplish the proposed federal 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. There are 14 Cooperating Agencies for the LTEMP EIS, which include the Bureau of Indian Affairs (BIA), U.S. Fish and Wildlife Service (FWS), Western Area Power Administration (WAPA), Arizona Game and Fish Department (AZGFD), Colorado River Board of California, Colorado River Commission of Nevada, Upper Colorado River Commission (UCRC), Salt River Project, Utah Associated

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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).

Municipal Power Systems, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and the Pueblo of Zuni.

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.

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 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 2013).

ES.2 PROPOSED FEDERAL ACTION

The proposed federal action considered in this EIS, as described in the 2011 Notice of Intent (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. Under the LTEMP, water will continue to be delivered 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 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 (Section ES.4.4).

ES.2.1 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.

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 Properties* (NRHP)-eligible properties, and protecting the interests of American Indian Tribes, while meeting obligations for water delivery and the generation of hydroelectric power.

ES.2.2 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 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, National Historic Preservation Act, CRSPA, and other applicable federal laws.

Reclamation and NPS developed resource goals considering public input and desired future conditions 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 (*Gila cypha*) 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 (*Oncorhychus mykiss*) 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.

ES.3 SCOPE OF THE EIS

ES.3.1 Affected Region and Resources

In general, the region examined in this EIS includes the area potentially directly 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, 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. Figure ES-1 portrays the project area in context with the geographic regions of northern Arizona, southwestern Utah, and southern Nevada.

ES.3.2 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

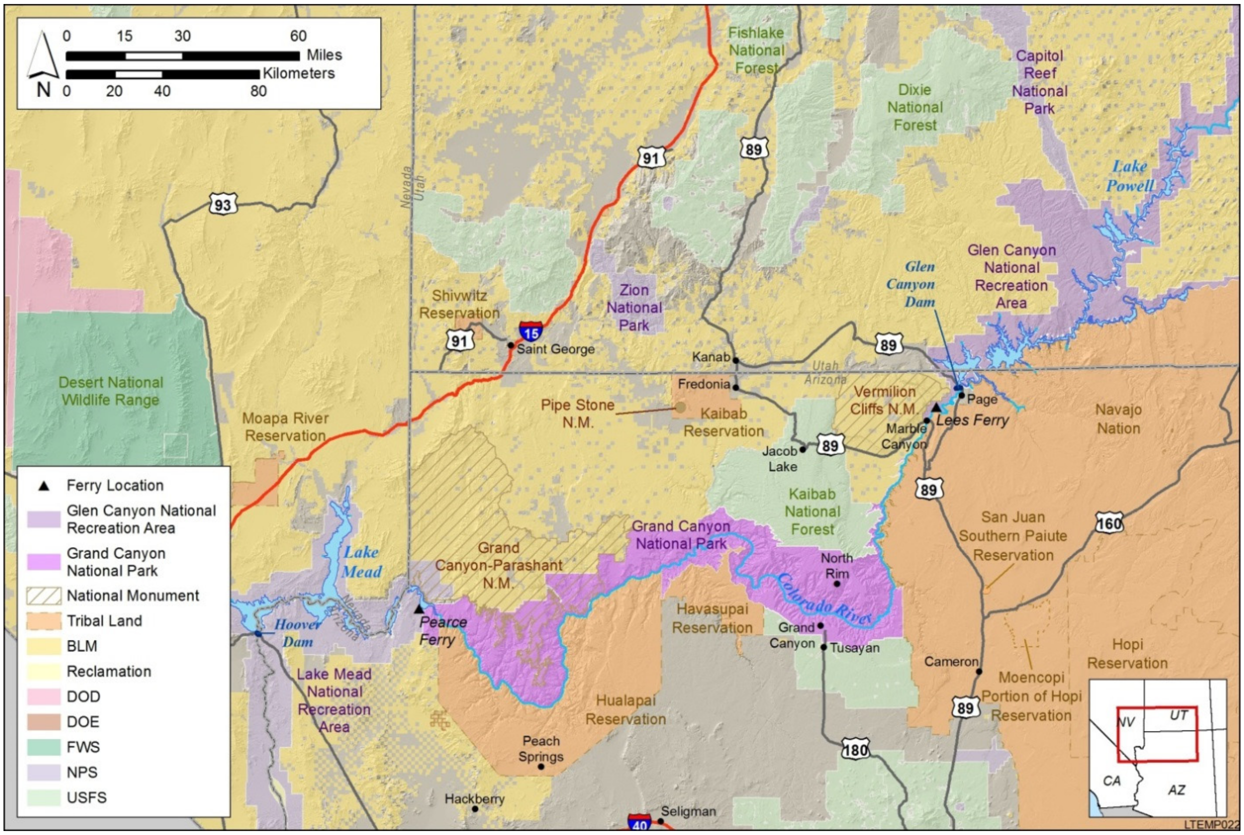

FIGURE ES-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands (This map is for illustrative purposes only, not for jurisdictional determinations; potential area of effects varies by resource.)

regulations. 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 [*Xyrauchen texanus*]), 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 (GHG) emissions and the effects of climate change on future impacts of Glen Canyon Dam operations.

ES.4 LAWS AND REGULATIONS RELATED TO OPERATIONS OF GLEN CANYON DAM AND PARK MANAGEMENT

The following laws, regulations, and treaties 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.

ES.4.1 Environmental Laws and Executive Orders

- Bald and Golden Eagle Protection Act of 1940, as amended 1962 (Title 16, *United States Code*, Section 668c [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 Statute [Stat.] 884)
- Executive Order (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 1994)
- 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.)
- 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)

ES.4.2 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., Public Law [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 (16 USC 470 et seq.; P.L. 89-665)

ES.4.3 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.)

ES.4.4 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)

ES.4.5 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 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 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.

ES.5 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.

ES.5.1 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 2007).
- Final Biological Opinion on the Operation of Glen Canyon Dam, including High-Flow Experiments and Nonnative Fish Control (FWS 2011). This replaced former Biological Opinions from 1995 to 2009.
- Final Biological Opinion on the Comprehensive Fisheries Management Plan, Coconino and Mohave Counties, Arizona (FWS 2013).

ES.5.2 Environmental Impact Statements and Related Documents

ES.5.2.1 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 Modified Low Fluctuating Flows (MLFF) as the operating system for the dam. A component of the final Glen Canyon Dam EIS (Reclamation 1995) and the environmental commitments identified in the 1996 ROD 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). As agreed to by the signatories of the original 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 36 CFR 800.14(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.

ES.5.2.2 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007b)

In 2007, Reclamation developed and adopted interim operational guidelines that would address the operation of Lake Powell and Lake Mead during drought and low-reservoir conditions. 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 (ICS), 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.

ES.5.2.3 Colorado River Management Plan: Final Environmental Impact Statement and Record of Decision (NPS 2005, 2006a)

This Final EIS (NPS 2005) 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 was 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.

ES.5.2.4 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.

ES.5.2.5 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.

ES.5.2.6 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.

ES.5.2.7 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.

ES.5.2.8 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.

ES.5.3 Environmental Assessments and Related Documents

ES.5.3.1 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 (*Salmo trutta*), 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.

ES.5.3.2 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.

ES.5.3.3 Environmental Assessment, Comprehensive Fisheries Management Plan for Grand Canyon National Park and Glen Canyon National Recreation Area (NPS 2013)

The NPS is implementing a CFMP, in coordination with the AZGFD, the FWS, Reclamation, and 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.

ES.5.3.4 Environmental Assessment and Assessment of Effect, Exotic Plant Management Plan Grand Canyon National Park, Arizona (NPS 2009)

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.

ES.5.4 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 the following.

ES.5.4.1 Colorado River Basin Salinity Control Program (Reclamation 2014)

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.

ES.5.4.2 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.

ES.5.4.3 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.

ES.5.4.4 Grand Canyon National Park Foundation Statement for Planning and Management (NPS 2010)

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.

ES.5.4.5 Glen Canyon National Recreation Area and Rainbow Bridge National Monument Foundation Document for Management and Planning (NPS 2014)

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.

ES.5.4.6 Management and Control of Tamarisk and Other Invasive Vegetation at Backcountry Seeps, Springs, and Tributaries in Grand Canyon National Park (NPS 2008)

GCNP'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.

ES.5.4.7 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.

ES.5.4.8 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.

ES.6 PUBLIC INVOLVEMENT

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. 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).

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. 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. Reclamation and NPS evaluated the feedback received at this meeting and used it to develop the final set of alternatives considered in this EIS.

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.Throughout the LTEMP development process, DOI had formal and informal consultations with Tribes.

On January 8, 2016, the LTEMP DEIS was filed with Region 9 of the U.S. Environmental Protection Agency, 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. 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).

The original 90-day public comment period was extended an additional 32 days (122 days 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. 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.

ES.7 DESCRIPTIONS OF ALTERNATIVES

Seven alternatives, including the No Action Alternative, were developed for consideration in the EIS. 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 (C, D [the preferred alternative], F, and G) were developed by the joint-lead agencies with various levels of participation by other DOI agencies, including the BIA, FWS, and GCMRC; as well as Argonne National Laboratory, WAPA, and 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, Wyoming, and the 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 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.

ES.7.1 Development of Alternatives

The alternative development process began with identification of the proposed action (i.e., development of a Long-Term Experimental and Management Plan), purpose and need of the LTEMP, and the resource goals and objectives of the LTEMP (Section ES.2). 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, and alternatives that had been identified in several efforts led by the GCDAMP (USGS 2006, 2008).

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 this EIS and received letters of support from WAPA, the Basin States, and the National Parks Conservation Association before the DEIS was published. DOI received both positive and negative feedback about this alternative from other stakeholders. Alternative D was developed by the DOI based on the results of the analysis impacts of the 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 used for other alternatives (Section ES.10), and these results served as the basis for the assessments presented in the EIS. Subsequent to that modeling, relatively minor modifications were made to Alternative D based on discussions with Cooperating Agencies, and with the support of additional modeling.

To aid in the alternative development process, formal decision analysis tools were used for the LTEMP EIS. Such tools are useful for this application 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.

ES.7.2 Descriptions of Alternatives Analyzed in the EIS

The EIS assesses the potential environmental effects of the seven alternatives considered for detailed analysis. 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, a new HFE protocol was developed that would replace the existing protocol developed in 2011.

- Nonnative fish control actions. Implementation of control actions for nonnative brown and rainbow trout are patterned after those identified in the Nonnative Fish Control EA (Reclamation 2011a) and FONSI (Reclamation 2012b). Some alternatives, however, 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.

- Conservation measures established by the FWS in previous Biological Opinions. Conservation measures identified in the 2011 Biological Opinion (BO) on operations of Glen Canyon Dam (FWS 2011) included the establishment of a humpback chub refuge, evaluation of the suitability of habitat in the lower Grand Canyon for the razorback sucker, 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). Additional conservation measures were developed for the preferred alternative during Endangered Species Act (ESA) Section 7 consultation with the FWS.

- 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 NRHP historic properties.

- Continued adaptive management under the GCDAMP, including a research and monitoring component.

With operational flows limited to 45,000 cfs and below, the overall extent of the riparian area in the 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 GCNP and 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 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 ES.5). The Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a), together with existing laws and regulations (Section ES.4), were used to establish sideboards that constrain the breadth and nature of flow and non-flow actions that were 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 CRSP facilities are typically provided by power resources in the Aspinall Unit, a series of three hydropower dams on the Gunnison River. However, under some relatively 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 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 NOI 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 NEPA evaluations and ESA Section 7 Biological Opinions 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 ES.6.2.1 to ES.6.2.7. Operational characteristics of LTEMP alternatives are presented in Table ES-1, and condition-dependent and experimental elements are summarized in Table ES-2.

ES.7.2.1 Alternative A (No Action Alternative)

Alternative A (No Action Alternative) represents continued operation of Glen Canyon Dam as guided by the 1996 ROD for operations of Glen Canyon Dam: 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 Lakes Powell and 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.

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.

Under Alternative A, the current HFE protocol (Reclamation 2011b) would be followed until it expired in 2020. Under this protocol, high-flow releases may be made in spring (March and April) or fall (October and November). HFE magnitude would range from 31,500 to 45,000 cfs. The duration would range from less than 1 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). Under the protocol, 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.

Under Alternative A, the current nonnative fish control protocol would be followed until it expired in 2020 (Reclamation 2011a). Mechanical removal would primarily consist of the use

TABLE ES-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 ES-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 trout management flows (see Table ES-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 ES-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 ES-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 ES-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 ES-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 trout management flows. Minimum monthly flow would be held constant on Saturdays and Sundays in May through Aug.	No.	No.	No.

TABLE ES-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 trout management flows under warm and cold conditions.	No.	Test and implement if successful.

TABLE ES-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 sub-adult 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, low humpback chub numbers. Objective: Increase number of adult and subadult humpback chub	Yes, if 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.	Yes, if 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.	Yes, if 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.	Yes, if trout numbers are above and humpback chub numbers are below tier 2 triggers in Little Colorado River reach.	Yes, if 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.	Yes, if 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 ES-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
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 trout management flows in a given year would consider the resource conditions as specified in Section ES.8.2 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, but 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).

of boat-mounted electrofishing equipment to remove all nonnative fish captured. 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).

ES.7.2.2 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. Alternative B focuses on non-flow actions and experiments to address sediment resources, nonnative fish control, and on native and nonnative fish communities.

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. 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.

Alternative B includes implementation of the nonnative fish control protocol (Reclamation 2011a) and HFE protocol (Reclamation 2011b) through the entire LTEMP period, but HFEs would be limited to a maximum of one spring or fall HFE every other year. In addition to these experimental actions, Alternative B would test trout management flows and hydropower improvement flows. With trout management flows, high flows (e.g., 20,000 cfs) would be maintained for 2 or 3 days, followed by a very sharp drop in flows to a minimum level (e.g., 5,000 cfs) for the purpose of reducing annual recruitment of trout. Hydropower improvement experiments would test maximum powerplant capacity releases in up to 4 years during the LTEMP period, but only in years with annual volumes ≤8.23 maf.

ES.7.2.3 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 flow and non-flow actions that would be triggered by resource conditions. The alternative uses decision trees to identify when experimental changes in base operations or 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.

Monthly release volumes under Alternative C 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. Under Alternative C, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to monthly volume (7× monthly volume in kaf). The down-ramp rate would be increased to 2,500 cfs/hr, but the up-ramp rate would remain unchanged at 4,000 cfs/hr.

Experimentation under Alternative C includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) 24-hr proactive spring HFEs, up to 45,000 cfs, in high-volume years (≥10 maf release volume); (3) extension of the possible duration of fall HFEs while maintaining a maximum total volume of a 96-hr 45,000-cfs release); (4) reducing fluctuations before and after HFEs; (5) mechanical removal of trout near the Little Colorado River confluence; (6) trout management flows; (7) low summer flows during the entire LTEMP period to allow greater warming; and (8) experimental vegetation treatments.

ES.7.2.4 Alternative D (Preferred Alternative)

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

After modeling of Alternative D was completed, several adjustments were made to specific operational and experimental characteristics based on discussions with Cooperating Agencies and stakeholders. These adjustments included (1) an increase in August release volume 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. 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 analysis did show that the adjustments could result in some changes to the expected impacts on sediment and hydropower resources.

Under Alternative D, the pattern of monthly releases would be relatively even compared to that 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 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 approximate WAPA's contract rate of delivery. 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. 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), up to a maximum of 8,000 cfs/day. The down-ramp rate would be increased to 2,500 cfs/hr, but the up-ramp rate would remain unchanged at 4,000 cfs/hr.

Experimentation under Alternative D includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) 24-hr proactive spring HFEs, up to 45,000 cfs, in high-volume years (≥10 maf release volume); (3) extension of the duration of up to 45,000-cfs fall HFEs to as many as 250 hr depending on sediment availability; (4) mechanical removal of nonnative fish near the Little Colorado River confluence; (5) trout management flows; (6) low summer flows in the second 10 years of the LTEMP period to allow greater warming; (7) macroinvertebrate production flows; and (8) experimental vegetation treatments.

ES.7.2.5 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.

Under Alternative E, monthly volumes would closely follow the monthly hydropower demand as defined by WAPA's contract rate of delivery. 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 possibility of the operational tier differing from that of Alternative A as established in the Interim Guidelines. In addition, lower monthly volumes (relative to Alternative A) would be targeted in August and September to reduce sediment transport during the monsoon period, when most sediment is delivered by the Paria River. 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). The down-ramp rate would be increased to 2,500 cfs/hr, but the up-ramp rate would remain unchanged at 4,000 cfs/hr.

Experimentation under Alternative E includes testing the effects of the following actions: (1) sediment-triggered fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) sediment-triggered spring HFEs, up to 45,000 cfs and 96 hr in duration, only in the second 10 years of the LTEMP period; (3) reducing fluctuations before fall HFEs; (4) mechanical removal of trout near the Little Colorado River confluence; (5) trout management flows; (6) low summer flows in the second 10 years of the LTEMP period to allow greater warming; and (7) experimental vegetation treatments.

ES.7.2.6 Alternative F

The objective of Alternative F is to a provide flows that follow a more natural pattern of high spring, and low summer, fall, and winter flows 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.

Under Alternative F, peak flows would be lower than pre-dam magnitudes to reduce sediment transport and erosion given the reduced sand supply downstream of the dam. 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) and 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 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. There would be no within-day fluctuations in flow under Alternative F.

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.

Experimentation under Alternative F includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 96 hr in duration, through the entire 20-year LTEMP period and (2) experimental vegetation treatments. 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.

ES.7.2.7 Alternative G

The objective of Alternative G is to maximize the conservation of sediment, in order to maintain and increase sandbar size. 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. In an 8.23-maf year, steady flow would be approximately 11,400 cfs.

Experimentation under Alternative G includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) 24-hr proactive spring HFEs, up to 45,000 cfs, in high-volume years (≥10 maf release volume); (3) extension of the duration of up to 45,000-cfs fall HFEs for as many as 250 hr depending on sediment availability; (4) mechanical removal of trout near the Little Colorado River confluence; (5) trout management flows; and (6) experimental vegetation treatments.

ES.8 IMPLEMENTATION OF THE LTEMP

Annually, Reclamation will develop a hydrograph based on the characteristics of the selected alternative. 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 the 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.

ES.8.1 Operational Flexibility

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.

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; and

- 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 CRSP dams.

In addition, Reclamation may make modifications under circumstances that may include operations that are prudent or necessary for 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.)

ES.8.2 Experimental Implementation Process

At various levels, all alternatives identify 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 (Table ES-2). These condition-dependent treatments would be implemented experimentally during the LTEMP period unless they prove ineffective or result in unanticipated and 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 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.

A condition-dependent adaptive design is considered 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.

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 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 alternatives in the LTEMP EIS.

In implementing the process described above, 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, 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 considering resource issues and 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 it 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.

ES.8.3 Descriptions of Potential Experiments

The following text describes specific experiments for 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. 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. Given the size of the project area and the variability inherent in the system, this pragmatic approach to experimentation is warranted, and 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.

ES.8.3.1 Sediment-Related Experiments

Under most alternatives, spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period 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 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 and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented.

Under Alternative D, the existing HFE protocol was updated and incorporated into the LTEMP process. 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 and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring or fall 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.

Alternatives differ with regard to inclusion of several additional experiments, including: (1) reduced within-day fluctuations (referred to as "load-following curtailment") before and/or after fall HFEs; (2) short-duration (24-hr) proactive spring HFEs in high-volume equalization years prior to equalization releases; and (3) implementation of extended-duration (>96-hr) HFEs, depending on sediment conditions (Table ES-2). The pattern of transferring water volumes from other months to make up the HFE volume would be addressed through a process like that described in Section ES.8.2, and, like that one, will involve consultation with DOI bureaus and Western.

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 potential unacceptable adverse impacts on the resources identified in Section ES7.2. Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted. Annual implementation of any experiments would consider resource condition assessments and resource concerns using the interagency process described in Section ES.8.2.

ES.8.3.2 Aquatic Resource-Related Experiments

Depending on the alternative, various aquatic resource-related experiments would be triggered by either estimated numbers of rainbow trout and other 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 for Alternative D were developed during formal Section 7 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 various alternatives include (1) trout management flows, (2) mechanical removal of trout, (3) low summer flows, and (3) macroinvertebrate production flows (Table ES-2). Aquatic resource experiments would seek to refine our understanding of the impacts of water releases, HFEs, and trout management flows 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.

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 ES.8.2. Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted. Annual implementation of any experiments would consider resource condition assessments and resource concerns using the interagency process described in Section ES.8.2.

ES.8.3.3 Experimental Vegetation Treatment

Experimental riparian vegetation treatments 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 GCNP and 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.

ES.8.3.4 Hydropower Improvement Flows

Alternative B includes testing maximum powerplant capacity releases in up to 4 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. 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.

ES.9 AFFECTED ENVIRONMENT

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 1 mi 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, 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.

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 is generally classified as semiarid and the Lower Basin 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 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.

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.

Post-dam water releases 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 less than this maximum range since implementation of the 1996 ROD (Reclamation 1996). These fluctuations result in a downstream "fluctuation zone" between low and high river stages (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. 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 8°C (46°F) year round, although releases 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 1999). 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. These changes in temperature and turbidity have important influences on the aquatic system downstream from the dam.

Hydropower is cleaner than nonrenewable fuel resources, and if water releases are less constrained, hydropower can be more responsive to changes in load than many other forms of electrical generation. The Glen Canyon Powerplant is an important component of the electrical power system of the western United States and is the largest hydroelectric facility in the CRSP. 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 operating policies allow, releases are scheduled to be higher during months when power demand is greatest, typically during the summer and winter.

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. Cold, clear releases support an important rainbow trout fishery in the Glen Canyon reach, while native fish, including the endangered humpback chub and razorback sucker, occur further downstream. Vegetation has become established closer to the river's edge due to the elimination of annual flood scouring, and has increasingly become dominated by nonnative plant species. Most cultural resources are located at higher elevations away from the area affected by dam operations, but at some locations, these operations may affect the availability of windblown sand that helps replenish eroded sites. Lake Powell, Lake Mead, and the Colorado River, which flows between the two reservoirs, support important recreational resources. This recreation and the hydropower produced by Glen Canyon Dam have important effects on the local and regional economy. All of these resources are of vital importance to the social and economic wellbeing of Tribes with ancestral ties to Glen and Grand Canyons.

ES.10 ENVIRONMENTAL CONSEQUENCES

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 affect flows and sediment distribution in the river channel and corridor, as well as 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.

The quantitative analyses used for the LTEMP EIS employed an integrated multiple-resource modeling framework that incorporated a series of linked models that explicitly accounted for the effects of dam operations and the linkages among resources (Figure ES-2). The assessment of resource impacts was based on these linkages under a common conceptual model.

This conceptual model was central to the construction of the LTEMP alternatives. Operational characteristics and experimental actions of each alternative target particular resource effects. Environmental effects caused by actions included in different alternatives 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.

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 ES-2). The magnitude of effects was estimated using quantifiable metrics for indicators of the condition of a resource. The environmental effects of alternatives were compared quantitatively whenever possible, on the basis of the estimated effect

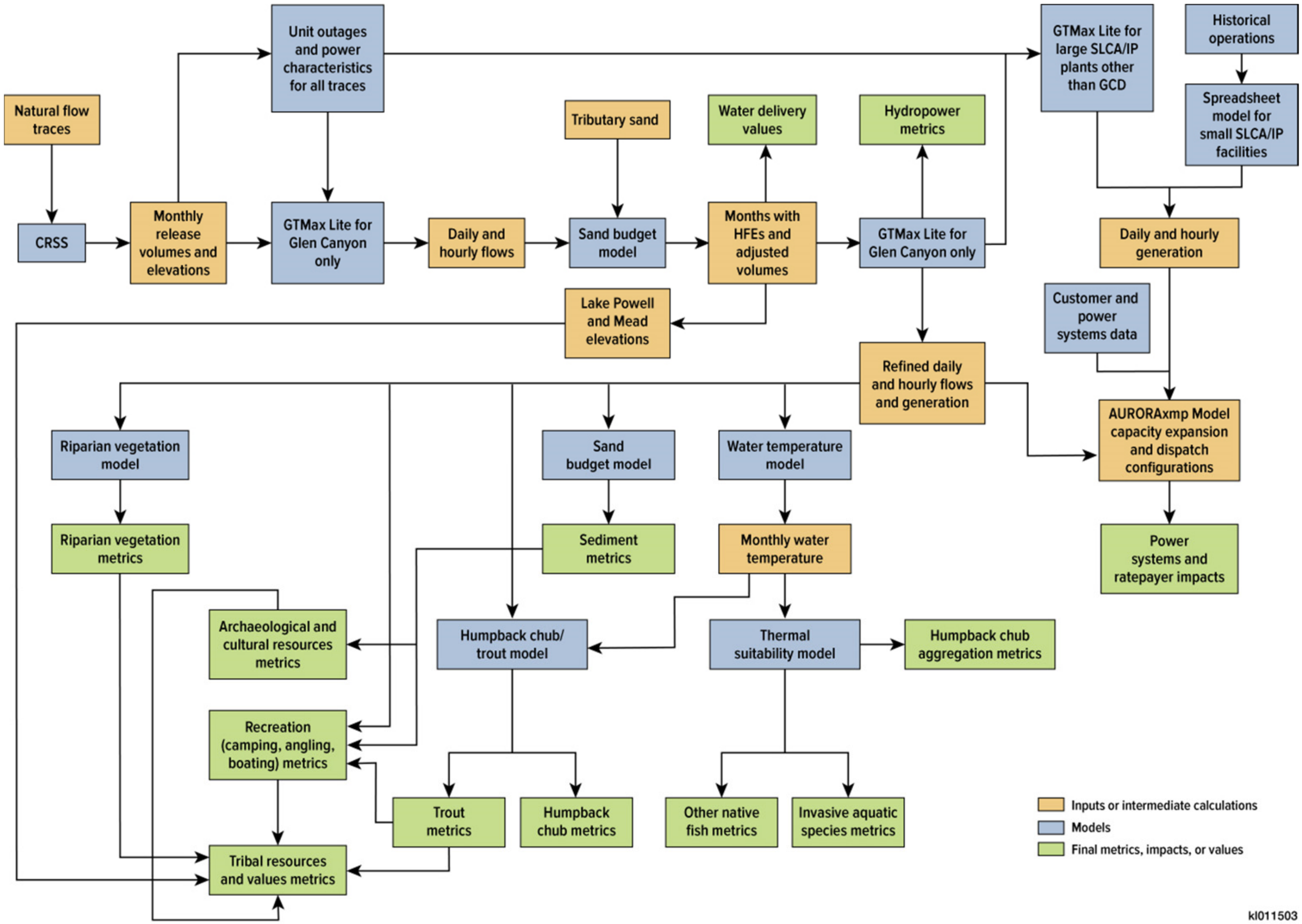

FIGURE ES-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output

on resource condition as measured by a set of resource metrics; these quantitative predictions were supported when possible by published observations and findings. It should be noted that the models used here are mainly intended to allow for relative comparisons among alternatives and not necessarily be predictive.

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 in-flow 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 to1930, 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 to 2010 and 1906 to 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.

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). In combination, the 21 hydrology traces and 3 sediment traces resulted in an analysis that considered 63 possible hydrology-sediment conditions. Models depicted in Figure ES-2 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.

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 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.

Information sources used for this analysis included observational and research data collected since the start of dam operations and resulting from research programs originating under the GCDAMP established under the 1996 ROD and carried out by the GCMRC and other researchers.

Table ES-3 presents a summary of impacts anticipated under each alternative by resource topic.

TABLE ES-3 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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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 ES-3 (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. The relative ranking of Alternative D compared to other alternatives would change from fourth to third lowest cost. These adjustments would also result in slight reductions to the retail rate costs. 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.

ES.11 UNAVOIDABLE ADVERSE IMPACTS

On the basis of the assessments conducted and summarized in Table ES-3, 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 GCPA) in hydropower production relative to pre-1996-ROD operations that more closely match 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 trout management flows 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), the 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.

ES.12 RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM PRODUCTIVITY

Under all alternatives, different restrictions on flow fluctuations result in trade-offs between peak hydropower production and productivity of the environment, which are 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, trout management flows, and 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.

ES.13 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 due to flows that reduce flexibility (e.g., lower summer flow or reduced fluctuations under certain alternatives) would create an irretrievable loss (see Table ES-3).

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 Table ES-3).

Archeological sites by their nature are non-renewable; therefore any loss due to dam operations would be irretrievable. See Table ES-3 for the relative performance of alternatives 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 GCDAMP 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.

ES.14 REFERENCES

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