

Glen Canyon Dam

Long-Term Experimental and Management Plan
Environmental Impact Statement



PUBLIC DRAFT

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

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Rafters: Grand Canyon National Park

1 **GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN**
2 **DRAFT ENVIRONMENTAL IMPACT STATEMENT**
3
4

5 **Joint-Lead Agencies**

6 Bureau of Reclamation
7 National Park Service
8

9 **Cooperating Agencies**

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

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11
12 **ABSTRACT**
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14

15 The U.S. Department of the Interior (DOI), through the Bureau of Reclamation and
16 National Park Service (NPS), proposes to develop and implement a Long-Term Experimental
17 and Management Plan (LTEMP) for operations of Glen Canyon Dam. The LTEMP would
18 provide a framework for adaptively managing Glen Canyon Dam operations over the next
19 20 years, consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions
20 of applicable federal law. The LTEMP would determine specific options for dam operations,
21 non-flow actions, and appropriate experimental and management actions that will meet the
22 GCPA's requirements and minimize impacts on resources within the area impacted by dam
23 operations, including those of importance to American Indian Tribes.
24

25 The Draft Environmental Impact Statement (DEIS) draws on the scientific information
26 that has been collected under the Glen Canyon Dam Adaptive Management Program over the
27 last 20 years to identify the potential environmental effects associated with taking no action, as
28 well as a reasonable range of alternatives to no action for implementing the proposed federal
29 action. The alternatives addressed in this DEIS include a broad range of operations and actions
30 that would meet the purpose, need, and objectives of the proposed federal action. The primary
31 resources that could be affected by the proposed action include sediment resources, aquatic and
32 terrestrial ecological resources, recreational resources, socioeconomic resources, hydropower
33 resources, resources of importance to American Indian Tribes, and historic and cultural resources
34 in the vicinity of the Glen and Grand Canyons. The DEIS has been developed in accordance with
35 the National Environmental Policy Act of 1969, as amended (NEPA), and follows the
36 implementing regulations developed by the President's Council on Environmental Quality in
37 Title 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations

1 implementing NEPA in 43 CFR Part 46. Based on the impact analyses conducted, DOI has
2 chosen Alternative D as the preferred alternative.

3
4 The review period for this DEIS will end 90 days after publication of the
5 U.S. Environmental Protection Agency Notice of Availability in the *Federal Register*. During
6 the 90-day comment period, comments will be accepted electronically through the NPS
7 Planning, Environment, and Public Comment website (<http://parkplanning.nps.gov/LTEMPEIS>)
8 and in hard copy delivered by the U.S. Postal Service or other mail delivery service. Written
9 comments will also be accepted during public meetings on the DEIS. Comments will not be
10 accepted by fax, by e-mail, or in any format other than those specified above. Bulk comments in
11 any format (hard copy or electronic) submitted on behalf of others will also not be accepted.

12
13 For additional information, visit <http://ltempeis.anl.gov> or contact:

14
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CONTENTS

1
2
3
4 ABSTRACT iii
5
6 ACRONYMS AND ABBREVIATIONS lxiii
7
8 1 INTRODUCTION 1-1
9
10 1.1 Description of the Proposed Action 1-4
11 1.2 Purpose of and Need for Action 1-5
12 1.3 Lead and Cooperating Agencies and Consulting Tribes 1-9
13 1.3.1 Lead Agencies 1-9
14 1.3.2 Cooperating Agencies and Consulting Tribes 1-9
15 1.4 Objectives and Resource Goals of the LTEMP 1-10
16 1.5 Scope of the DEIS 1-12
17 1.5.1 Affected Region and Resources 1-13
18 1.5.2 Impact Topics Selected for Detailed Analysis 1-14
19 1.5.3 Impact Topics Dismissed from Detailed Analysis 1-15
20 1.6 Role of Adaptive Management 1-16
21 1.6.1 History of the Existing Adaptive Management Program 1-16
22 1.6.2 Relationship of Adaptive Management to NEPA and Changes
23 to Operations 1-17
24 1.7 Role of Decision Analysis in the DEIS Process 1-17
25 1.8 History, Location, and Setting 1-18
26 1.8.1 History and Purpose of Glen Canyon Dam 1-18
27 1.8.2 Location of Glen Canyon Dam and LTEMP Affected Area 1-19
28 1.8.3 Operation of the Glen Canyon Dam 1-20
29 1.8.4 History, Purpose, and Significance of the National Park System
30 Units 1-22
31 1.8.4.1 Grand Canyon National Park 1-22
32 1.8.4.2 Glen Canyon National Recreation Area 1-24
33 1.8.4.3 Lake Mead National Recreation Area 1-24
34 1.8.5 Tribal Lands 1-25
35 1.8.5.1 Navajo Nation 1-26
36 1.8.5.2 Hualapai 1-26
37 1.8.5.3 Havasupai 1-26
38 1.8.5.4 Southern Paiute Tribes 1-27
39 1.8.5.5 Hopi 1-28
40 1.8.5.6 Pueblo of Zuni 1-28
41 1.8.5.7 Fort Mojave 1-29
42 1.9 Laws and Regulations Related to Operations of Glen Canyon Dam and
43 Park Management 1-29
44 1.9.1 Environmental Laws and Executive Orders 1-29
45 1.9.2 Cultural/Historical Laws and Executive Orders 1-30
46

CONTENTS (Cont.)

1
 2
 3
 4 1.9.3 American Indian and Tribal Consultation Laws and Executive
 5 Orders..... 1-30
 6 1.9.4 Law of the River 1-31
 7 1.10 Related Actions 1-31
 8 1.10.1 Biological Opinions 1-31
 9 1.10.2 Environmental Impact Statements and Related Documents..... 1-31
 10 1.10.3 Environmental Assessments and Related Documents 1-35
 11 1.10.4 Other Actions, Programs, Plans, and Projects 1-35
 12
 13 2 DESCRIPTION OF ALTERNATIVES 2-1
 14
 15 2.1 Development of Alternatives..... 2-2
 16 2.2 Descriptions of Alternatives Considered in Detail..... 2-4
 17 2.2.1 Alternative A (No Action Alternative) 2-8
 18 2.2.2 Alternative B..... 2-19
 19 2.2.3 Alternative C..... 2-22
 20 2.2.3.1 Base Operations under Alternative C 2-24
 21 2.2.3.2 Experimental Framework for Alternative C..... 2-26
 22 2.2.4 Alternative D (Preferred Alternative) 2-42
 23 2.2.4.1 Base Operations under Alternative D..... 2-42
 24 2.2.4.2 Operational Flexibility under Alternative D 2-43
 25 2.2.4.3 Experimental Framework for Alternative D 2-46
 26 2.2.5 Alternative E..... 2-69
 27 2.2.5.1 Base Operations under Alternative E 2-69
 28 2.2.5.2 Experimental Framework for Alternative E..... 2-72
 29 2.2.6 Alternative F 2-77
 30 2.2.7 Alternative G..... 2-78
 31 2.3 Alternatives Considered and Eliminated from Detailed Study 2-81
 32 2.3.1 Modified Low Fluctuating Flows with Extended Protocols 2-81
 33 2.3.2 Naturally Patterned Flow Alternative 2-82
 34 2.3.3 Seasonal Fluctuations with Low Summer Flow Alternative 2-82
 35 2.3.4 Grand Canyon First! Alternative 2-83
 36 2.3.5 Species Community and Habitat-Based Alternative..... 2-83
 37 2.3.6 Stewardship Alternative..... 2-83
 38 2.3.7 Twelve-Year Experiment of Two Steady-Flow Alternatives 2-84
 39 2.3.8 Decommission Glen Canyon Dam Alternative..... 2-84
 40 2.3.9 Fill Lake Mead First Alternative..... 2-85
 41 2.3.10 Full-Powerplant Capacity Operations Alternative..... 2-85
 42 2.3.11 Run-of-the-River Alternative..... 2-85
 43 2.4 Alternative Elements Eliminated from Detailed Study 2-86
 44 2.4.1 New Infrastructure 2-86
 45 2.4.2 Flow and Non-Flow Actions..... 2-87
 46 2.5 Summary Comparison of Alternatives 2-88

CONTENTS (Cont.)

1
 2
 3
 4 3 AFFECTED ENVIRONMENT 3-1
 5
 6 3.1 Project Area 3-1
 7 3.1.1 Geologic Setting 3-1
 8 3.1.2 Climatic Setting 3-3
 9 3.1.3 Colorado River Ecosystem Resource Linkages 3-3
 10 3.1.3.1 Water Release Characteristics 3-4
 11 3.2 Water Resources 3-5
 12 3.2.1 Hydrology 3-5
 13 3.2.1.1 Lake Powell Hydrology 3-6
 14 3.2.1.2 Hydrology of the Colorado River Downstream of Glen
 15 Canyon Dam 3-9
 16 3.2.1.3 Lake Mead Hydrology 3-11
 17 3.2.1.4 Seeps and Springs 3-12
 18 3.2.2 Water Quality 3-14
 19 3.2.2.1 Lake Powell Water Quality 3-14
 20 3.2.2.2 Colorado River Water Quality 3-16
 21 3.2.2.3 Lake Mead Water Quality 3-24
 22 3.2.3 Tribal Perspectives on Water Resources 3-27
 23 3.2.4 Hydrology and Climate Change 3-28
 24 3.2.4.1 Basis for Runoff Estimates 3-29
 25 3.2.4.2 Water Variability and Availability 3-29
 26 3.2.4.3 Seasonal Timing Shifts 3-31
 27 3.2.4.4 Water Quality 3-31
 28 3.3 Sediment Resources 3-32
 29 3.3.1 Background: Geomorphology of the Colorado River 3-32
 30 3.3.1.1 Geomorphic Features of the Colorado River 3-33
 31 3.3.1.2 Glen Canyon Geomorphology 3-36
 32 3.3.1.3 Marble and Grand Canyon Geomorphology 3-37
 33 3.3.2 Sediment Characteristics and Transport Mechanisms 3-39
 34 3.3.2.1 Sediment Sources 3-43
 35 3.3.2.2 Sediment Transport and Storage 3-46
 36 3.3.2.3 Lake Deltas 3-52
 37 3.4 Natural Processes 3-54
 38 3.5 Aquatic Ecology 3-55
 39 3.5.1 Aquatic Food Base 3-56
 40 3.5.1.1 Periphyton and Rooted Aquatic Plants 3-57
 41 3.5.1.2 Plankton 3-59
 42 3.5.1.3 Macroinvertebrates 3-59
 43 3.5.1.4 Nonnative Invasive Species 3-61
 44 3.5.1.5 Food Web Dynamics 3-65
 45 3.5.2 Native Fish 3-65
 46 3.5.2.1 Special Status Fish Species 3-67

CONTENTS (Cont.)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46

3.5.2.2	Other Native Species	3-81
3.5.3	Nonnative Fish	3-85
3.5.3.1	Coldwater Nonnative Species	3-89
3.5.3.2	Warmwater Nonnative Species	3-95
3.5.3.3	Interactions with Native Species	3-97
3.5.3.4	Nonnative Fish Control Activities and Effects of Flow Conditions	3-99
3.6	Vegetation	3-104
3.6.1	Historic and Remnant Riparian Plant Communities	3-104
3.6.2	Existing Riparian Vegetation Downstream from Glen Canyon Dam	3-106
3.6.2.1	Tribal Perspectives on Vegetation	3-114
3.6.3	Special Status Plant Species	3-115
3.7	Wildlife	3-115
3.7.1	Invertebrates	3-118
3.7.2	Amphibians and Reptiles	3-120
3.7.3	Birds	3-121
3.7.4	Mammals	3-122
3.7.4.1	Tribal Perspectives on Wildlife Species	3-125
3.7.5	Special Status Wildlife Species	3-126
3.7.5.1	Invertebrates	3-126
3.7.5.2	Amphibians and Reptiles	3-129
3.7.5.3	Birds	3-131
3.7.5.4	Mammals	3-137
3.8	Cultural Resources	3-137
3.8.1	Area of Potential Effect	3-139
3.8.2	Description of Cultural Resources and Site Types	3-140
3.8.2.1	Archaeological Resources	3-142
3.8.2.2	Historic Resources	3-146
3.8.2.3	Cultural Landscapes	3-147
3.8.2.4	Traditional Cultural Properties and Ethnographic Resources	3-148
3.9	Tribal Cultural Resources	3-149
3.9.1	Havasupai	3-149
3.9.2	Hualapai	3-150
3.9.3	Southern Paiute Tribes	3-153
3.9.4	Hopi	3-153
3.9.5	Navajo Nation	3-154
3.9.6	Zuni	3-156
3.9.7	Fort Mojave Indian Tribe	3-159
3.9.8	Indian Trust Assets and Trust Responsibility	3-160
3.10	Recreation, Visitor Use, and Experience	3-160
3.10.1	Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area	3-160

CONTENTS (Cont.)

1
2
3
4 3.10.1.1 Recreational Fishery..... 3-161
5 3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon
6 Reach..... 3-166
7 3.10.2 The Colorado River in Grand Canyon National Park..... 3-169
8 3.10.3 Recreation Use on Lakes Mead and Powell 3-178
9 3.10.3.1 Lake Mead National Recreation Area..... 3-178
10 3.10.3.2 Lake Powell, Glen Canyon National Recreation Area..... 3-179
11 3.11 Wilderness..... 3-180
12 3.11.1 Law and Policy 3-180
13 3.11.2 Defining Wilderness Character..... 3-181
14 3.12 Visual Resources..... 3-184
15 3.12.1 Glen Canyon National Recreation Area 3-185
16 3.12.2 Grand Canyon and the Colorado River..... 3-185
17 3.12.3 Lake Mead National Recreation Area..... 3-190
18 3.13 Hydropower..... 3-190
19 3.13.1 Power Operations..... 3-191
20 3.13.1.1 Hydropower Generation..... 3-191
21 3.13.1.2 Basin Fund..... 3-192
22 3.13.1.3 Operational Flexibility 3-192
23 3.13.1.4 Scheduling..... 3-194
24 3.13.1.5 Load/Generation Following and Regulation 3-194
25 3.13.1.6 Capacity Reserves 3-196
26 3.13.1.7 Disturbances and Emergencies and Outage Assistance..... 3-196
27 3.13.1.8 Transmission System..... 3-197
28 3.13.2 Power Marketing..... 3-197
29 3.13.2.1 Wholesale Rates 3-200
30 3.13.2.2 Retail Rates..... 3-201
31 3.14 Socioeconomics and Environmental Justice 3-201
32 3.14.1 The Six-County Region of Influence..... 3-201
33 3.14.1.1 Population..... 3-202
34 3.14.1.2 Income..... 3-202
35 3.14.1.3 Employment 3-204
36 3.14.1.4 Unemployment..... 3-206
37 3.14.1.5 Environmental Justice 3-206
38 3.14.2 The Seven-State Region of Influence 3-213
39 3.14.2.1 Population..... 3-213
40 3.14.2.2 Income..... 3-214
41 3.14.2.3 Employment 3-215
42 3.14.2.4 Unemployment..... 3-217
43 3.14.2.5 Environmental Justice 3-217
44 3.15 Air Quality..... 3-219
45 3.15.1 Local Air Quality 3-220
46 3.15.2 Regional Air Quality..... 3-221

CONTENTS (Cont.)

1
 2
 3
 4 3.15.3 Regional Air Emissions 3-224
 5 3.16 Climate Change 3-226
 6
 7 4 ENVIRONMENTAL CONSEQUENCES 4-1
 8
 9 4.1 Overall Analysis and Assessment Approach..... 4-1
 10 4.2 Water Resources..... 4-7
 11 4.2.1 Analysis Methods..... 4-8
 12 4.2.1.1 Hydrology..... 4-8
 13 4.2.1.2 Water Quality 4-11
 14 4.2.2 Summary of Impacts 4-12
 15 4.2.2.1 Hydrology..... 4-12
 16 4.2.2.2 Water Quality 4-34
 17 4.2.3 Alternative-Specific Impacts 4-44
 18 4.2.3.1 Alternative A (No Action Alternative)..... 4-44
 19 4.2.3.2 Alternative B 4-46
 20 4.2.3.3 Alternative C 4-49
 21 4.2.3.4 Alternative D (Preferred Alternative)..... 4-52
 22 4.2.3.5 Alternative E..... 4-54
 23 4.2.3.6 Alternative F..... 4-56
 24 4.2.3.7 Alternative G 4-59
 25 4.3 Sediment Resources 4-61
 26 4.3.1 Analysis Methods..... 4-62
 27 4.3.2 Summary of Impacts 4-66
 28 4.3.3 Alternative-Specific Impacts 4-68
 29 4.3.3.1 Alternative A (No Action Alternative)..... 4-71
 30 4.3.3.2 Alternative B 4-73
 31 4.3.3.3 Alternative C 4-76
 32 4.3.3.4 Alternative D (Preferred Alternative)..... 4-77
 33 4.3.3.5 Alternative E..... 4-80
 34 4.3.3.6 Alternative F..... 4-81
 35 4.3.3.7 Alternative G 4-82
 36 4.4 Natural Processes 4-83
 37 4.4.1 Analysis Methods..... 4-84
 38 4.4.2 Summary of Impacts 4-84
 39 4.4.3 Alternative-Specific Impacts 4-92
 40 4.4.3.1 Alternative A (No Action Alternative)..... 4-92
 41 4.4.3.2 Alternative B 4-92
 42 4.4.3.3 Alternative C 4-93
 43 4.4.3.4 Alternative D (Preferred Alternative)..... 4-94
 44 4.4.3.5 Alternative E..... 4-94
 45 4.4.3.6 Alternative F..... 4-95
 46 4.4.3.7 Alternative G 4-96

CONTENTS (Cont.)

1
2
3
4 4.5 Aquatic Ecology 4-97
5 4.5.1 Analysis Methods..... 4-97
6 4.5.1.1 Aquatic Food Base 4-97
7 4.5.1.2 Nonnative Fish 4-98
8 4.5.1.3 Native Fish 4-100
9 4.5.1.4 Aquatic Parasites 4-101
10 4.5.2 Summary of Impacts 4-102
11 4.5.2.1 Aquatic Food Base 4-102
12 4.5.2.2 Nonnative Fish 4-112
13 4.5.2.3 Native Fish 4-120
14 4.5.2.4 Aquatic Parasites 4-128
15 4.5.3 Alternative-Specific Impacts on Aquatic Resources 4-129
16 4.5.3.1 Alternative A (No Action Alternative)..... 4-129
17 4.5.3.2 Alternative B 4-132
18 4.5.3.3 Alternative C 4-135
19 4.5.3.4 Alternative D (Preferred Alternative)..... 4-138
20 4.5.3.5 Alternative E..... 4-142
21 4.5.3.6 Alternative F..... 4-145
22 4.5.3.7 Alternative G 4-148
23 4.6 Vegetation 4-151
24 4.6.1 Analysis Methods..... 4-151
25 4.6.2 Summary of Impacts 4-157
26 4.6.2.1 Impacts on Old High Water Zone Vegetation..... 4-157
27 4.6.2.2 Impacts on New High Water Zone..... 4-165
28 4.6.2.3 Wetlands 4-170
29 4.6.2.4 Special Status Plant Species 4-172
30 4.6.3 Alternative-Specific Impacts 4-175
31 4.6.3.1 Alternative A (No Action Alternative)..... 4-175
32 4.6.3.2 Alternative B 4-176
33 4.6.3.3 Alternative C 4-178
34 4.6.3.4 Alternative D (Preferred Alternative)..... 4-179
35 4.6.3.5 Alternative E..... 4-181
36 4.6.3.6 Alternative F..... 4-183
37 4.6.3.7 Alternative G 4-184
38 4.7 Wildlife..... 4-186
39 4.7.1 Analysis Methods..... 4-186
40 4.7.2 Summary of Impacts 4-187
41 4.7.2.1 Terrestrial Invertebrates 4-188
42 4.7.2.2 Amphibians and Reptiles..... 4-193
43 4.7.2.3 Birds 4-195
44 4.7.2.4 Mammals 4-197
45 4.7.2.5 Special Status Species 4-198
46 4.7.3 Alternative-Specific Impacts on Wildlife 4-210

CONTENTS (Cont.)

1			
2			
3			
4		4.7.3.1	Alternative A (No Action Alternative)..... 4-210
5		4.7.3.2	Alternative B 4-211
6		4.7.3.3	Alternative C 4-212
7		4.7.3.4	Alternative D (Preferred Alternative)..... 4-213
8		4.7.3.5	Alternative E..... 4-214
9		4.7.3.6	Alternative F..... 4-215
10		4.7.3.7	Alternative G 4-216
11	4.8		Cultural Resources 4-217
12		4.8.1	Compliance with Federal Regulations 4-217
13		4.8.2	Analysis Methods..... 4-217
14		4.8.3	Summary of Impacts 4-220
15		4.8.4	Alternative-Specific Impacts 4-226
16		4.8.4.1	Alternative A (No Action Alternative)..... 4-226
17		4.8.4.2	Alternative B 4-227
18		4.8.4.3	Alternative C 4-228
19		4.8.4.4	Alternative D (Preferred Alternative)..... 4-228
20		4.8.4.5	Alternative E..... 4-229
21		4.8.4.6	Alternative F..... 4-230
22		4.8.4.7	Alternative G 4-230
23	4.9		Tribal Resources..... 4-231
24		4.9.1	Tribal Resource Goals..... 4-231
25		4.9.1.1	Increase the Health of the Ecosystem in Glen, Marble, and
26			Grand Canyons 4-232
27		4.9.1.2	Protect and Preserve Sites of Cultural Importance..... 4-235
28		4.9.1.3	Preserve and Enhance Respect for Canyon Life 4-236
29		4.9.1.4	Preserve and Enhance the Sacred Integrity of Glen,
30			Marble, and Grand Canyons..... 4-238
31		4.9.1.5	Maintain and Enhance Healthy Stewardship Opportunities
32			and Maintain and Enhance Tribal Connections to the
33			Canyons 4-239
34		4.9.1.6	Economic Opportunity 4-240
35		4.9.1.7	Maintain Tribal Water Rights and Supply 4-240
36		4.9.1.8	LTEMP Process..... 4-241
37		4.9.2	Analysis Methods..... 4-241
38		4.9.3	Summary of Impacts 4-242
39		4.9.4	Alternative-Specific Impacts 4-247
40		4.9.4.1	Alternative A (No Action Alternative)..... 4-247
41		4.9.4.2	Alternative B 4-249
42		4.9.4.3	Alternative C 4-250
43		4.9.4.4	Alternative D (Preferred Alternative)..... 4-251
44		4.9.4.5	Alternative E..... 4-253
45		4.9.4.6	Alternative F..... 4-254
46		4.9.4.7	Alternative G 4-255

CONTENTS (Cont.)

1
2
3
4 4.10 Recreation, Visitor Use, and Experience..... 4-257
5 4.10.1 Analysis Methods..... 4-257
6 4.10.2 Summary of Impacts..... 4-258
7 4.10.2.1 Glen Canyon Fishing..... 4-264
8 4.10.2.2 Glen Canyon Day Rafting..... 4-266
9 4.10.2.3 Glen Canyon Recreational Facilities..... 4-266
10 4.10.2.4 Whitewater Boating..... 4-267
11 4.10.2.5 Lake Activities and Facilities..... 4-268
12 4.10.2.6 Tribal Recreation Operations..... 4-268
13 4.10.2.7 Pearce Ferry..... 4-269
14 4.10.2.8 Park Operations and Management..... 4-270
15 4.10.3 Alternative-Specific Impacts..... 4-270
16 4.10.3.1 Alternative A (No Action Alternative)..... 4-270
17 4.10.3.2 Alternative B..... 4-272
18 4.10.3.3 Alternative C..... 4-273
19 4.10.3.4 Alternative D (Preferred Alternative)..... 4-275
20 4.10.3.5 Alternative E..... 4-276
21 4.10.3.6 Alternative F..... 4-277
22 4.10.3.7 Alternative G..... 4-278
23 4.11 Wilderness..... 4-280
24 4.11.1 Analysis Methods..... 4-280
25 4.11.2 Summary of Impacts..... 4-281
26 4.11.3 Alternative-Specific Impacts..... 4-286
27 4.11.3.1 Alternative A (No Action Alternative)..... 4-286
28 4.11.3.2 Alternative B..... 4-287
29 4.11.3.3 Alternative C..... 4-288
30 4.11.3.4 Alternative D (Preferred Alternative)..... 4-288
31 4.11.3.5 Alternative E..... 4-289
32 4.11.3.6 Alternative F..... 4-290
33 4.11.3.7 Alternative G..... 4-291
34 4.12 Visual Resources..... 4-292
35 4.13 Hydropower..... 4-294
36 4.13.1 Analysis Methods..... 4-294
37 4.13.1.1 Hydropower Resource and Capacity Expansion Impacts..... 4-295
38 4.13.1.2 Wholesale Rate Impacts..... 4-301
39 4.13.1.3 Retail Rate Impacts..... 4-303
40 4.13.1.4 Hoover Dam Impacts..... 4-305
41 4.13.2 Summary of Hydropower Impacts..... 4-306
42 4.13.2.1 Monthly Water Release Impacts..... 4-306
43 4.13.2.2 Hydropower Power Generation and Capacity Impacts..... 4-310
44 4.13.2.3 Economic Impacts..... 4-312
45 4.13.2.4 Change in FES Wholesale Rates..... 4-315
46 4.13.2.5 Retail Rate and Bills Impacts..... 4-315

CONTENTS (Cont.)

1
2
3
4 4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power
5 Economics 4-316
6 4.13.3 Alternative-Specific Impacts 4-317
7 4.13.3.1 Alternative A (No Action Alternative)..... 4-317
8 4.13.3.2 Alternative B 4-318
9 4.13.3.3 Alternative C 4-319
10 4.13.3.4 Alternative D (Preferred Alternative)..... 4-320
11 4.13.3.5 Alternative E..... 4-321
12 4.13.3.6 Alternative F..... 4-322
13 4.13.3.7 Alternative G 4-323
14 4.14 Socioeconomics and Environmental Justice 4-324
15 4.14.1 Analysis Methods..... 4-324
16 4.14.1.1 Recreational Use Values 4-325
17 4.14.1.2 Recreational Economic Impacts 4-326
18 4.14.1.3 Electricity Bill Increase and Generation Capacity
19 Expansion Impacts 4-326
20 4.14.1.4 Environmental Justice 4-327
21 4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice ... 4-327
22 4.14.2.1 Recreational Use Values 4-327
23 4.14.2.2 Recreational Economic Impacts 4-338
24 4.14.2.3 Customer Utility Electricity Generation Capacity and
25 Residential Rate Increase Impacts..... 4-340
26 4.14.2.4 Environmental Justice Impacts..... 4-342
27 4.14.3 Alternative-Specific Impacts 4-348
28 4.14.3.1 Alternative A (No Action Alternative)..... 4-348
29 4.14.3.2 Alternative B 4-349
30 4.14.3.3 Alternative C 4-350
31 4.14.3.4 Alternative D (Preferred Alternative)..... 4-352
32 4.14.3.5 Alternative E..... 4-353
33 4.14.3.6 Alternative F..... 4-355
34 4.14.3.7 Alternative G 4-357
35 4.15 Air Quality..... 4-358
36 4.15.1 Analysis Methods..... 4-358
37 4.15.2 Summary of Impacts 4-360
38 4.15.3 Alternative-Specific Impacts 4-365
39 4.15.3.1 Alternative A (No Action Alternative)..... 4-366
40 4.15.3.2 Alternative B 4-366
41 4.15.3.3 Alternative C 4-366
42 4.15.3.4 Alternative D (Preferred Alternative)..... 4-366
43 4.15.3.5 Alternative E..... 4-367
44 4.15.3.6 Alternative F..... 4-367
45 4.15.3.7 Alternative G 4-367
46 4.16 Climate Change 4-368

CONTENTS (Cont.)

1
2
3
4 4.16.1 Analysis Methods..... 4-368
5 4.16.1.1 Effects of LTEMP Alternatives on Climate Change..... 4-368
6 4.16.1.2 Effects of Climate Change on Hydrology and Downstream
7 Resources..... 4-369
8 4.16.2 Summary of Impacts..... 4-370
9 4.16.2.1 Effects of LTEMP Alternatives on Climate Change..... 4-370
10 4.16.2.2 Effects of Climate Change on Hydrology and Downstream
11 Resources..... 4-375
12 4.16.3 Alternative-Specific Impacts 4-377
13 4.16.3.1 Alternative A (No Action Alternative)..... 4-377
14 4.16.3.2 Alternative B 4-377
15 4.16.3.3 Alternative C 4-380
16 4.16.3.4 Alternative D (Preferred Alternative)..... 4-380
17 4.16.3.5 Alternative E..... 4-381
18 4.16.3.6 Alternative F..... 4-381
19 4.16.3.7 Alternative G 4-382
20 4.17 Cumulative Impacts..... 4-382
21 4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting
22 Cumulative Impacts 4-382
23 4.17.1.1 Past and Present (Ongoing) Actions..... 4-391
24 4.17.1.2 Reasonably Foreseeable Future Actions 4-395
25 4.17.2 Climate-Related Changes..... 4-398
26 4.17.3 Cumulative Impacts Summary by Resource..... 4-398
27 4.17.3.1 Water Resources..... 4-407
28 4.17.3.2 Sediment Resources 4-408
29 4.17.3.3 Natural Processes 4-409
30 4.17.3.4 Aquatic Ecology..... 4-409
31 4.17.3.5 Vegetation 4-412
32 4.17.3.6 Wildlife..... 4-413
33 4.17.3.7 Cultural Resources 4-416
34 4.17.3.8 Tribal Resources..... 4-417
35 4.17.3.9 Recreation, Visitor Use, and Experience..... 4-418
36 4.17.3.10 Wilderness..... 4-419
37 4.17.3.11 Visual Resources 4-420
38 4.17.3.12 Hydropower..... 4-421
39 4.17.3.13 Socioeconomics and Environmental Justice 4-422
40 4.17.3.14 Air Quality and Climate Change 4-422
41 4.18 Unavoidable Adverse Impacts..... 4-423
42 4.19 Relationship between Short-Term Use and Long-Term Productivity..... 4-424
43 4.20 Irreversible and Irretrievable Commitments of Resources..... 4-425
44
45

CONTENTS (Cont.)

1
 2
 3
 4 5 CONSULTATION AND COORDINATION 5-1
 5
 6 5.1 Consultation and Coordination with Other Agencies and Programs 5-1
 7 5.1.1 U.S. Department of the Interior 5-1
 8 5.1.2 Cooperating Agencies 5-1
 9 5.1.3 American Indian Tribes 5-2
 10 5.1.4 Other Consultations 5-6
 11 5.1.4.1 National Historic Preservation Act 5-6
 12 5.1.4.2 State and Local Water and Power Agency Coordination 5-7
 13 5.1.4.3 U.S. Fish and Wildlife Service 5-7
 14 5.2 Public Involvement 5-8
 15 5.2.1 Public Scoping Process and Comments Received 5-8
 16 5.2.2 Public Meetings on Alternatives 5-10
 17 5.2.3 Glen Canyon Dam Adaptive Management Working Group 5-11
 18 5.3 Distribution of the LTEMP DEIS 5-11
 19
 20 6 REFERENCES 6-1
 21
 22 7 LIST OF PREPARERS 7-1
 23
 24 8 GLOSSARY 8-1
 25
 26 APPENDIX A: Adaptive Management Working Group Desired Future Conditions A-1
 27
 28 A.1 Desired Future Conditions: Colorado River Ecosystem A-5
 29 A.1.1 DFC Description A-5
 30 A.1.2 DFC Background and Legislation A-6
 31 A.1.3 Why the Colorado River Ecosystem DFCs Are Important A-6
 32 A.1.4 Colorado River Ecosystem DFCs A-6
 33 A.1.4.1 Sediment-Related Resources DFCs A-6
 34 A.1.4.2 Water Quality DFCs A-7
 35 A.1.4.3 Colorado River Ecosystem Aquatic Resource DFCs A-7
 36 A.1.4.4 Colorado River Ecosystem Riparian Resource DFCs A-9
 37 A.1.5 Colorado River Ecosystem DFCs Additional Information A-9
 38 A.1.5.1 Colorado River Ecosystem Linkages A-9
 39 A.1.5.2 Colorado River Ecosystem Metrics A-10
 40 A.2 Power Desired Future Conditions A-10
 41 A.2.1 Power DFC Description A-10
 42 A.2.2 Power DFC Background and Legislation A-10
 43 A.2.3 Why the Power DFC Is Important A-11
 44 A.2.4 Power DFCs A-11
 45 A.2.5 Power DFC Additional Information A-12
 46 A.2.5.1 Power Linkages A-12

CONTENTS (Cont.)

1			
2			
3			
4		A.2.5.2 Power Metrics.....	A-12
5	A.3	Cultural Resources Desired Future Conditions	A-13
6		A.3.1 Cultural Resources DFC Description.....	A-13
7		A.3.2 DFC Background and Legislation	A-13
8		A.3.3 Why the Cultural Resources DFCs Are Important	A-13
9		A.3.4 NRHP Eligible Historic Properties DFCs.....	A-14
10		A.3.4.1 Prehistoric Archaeological Sites and Historic Sites	A-14
11		A.3.4.2 Traditional Cultural Properties.....	A-14
12		A.3.5 NRHP Eligible Historic Properties DFC Additional Information	A-15
13		A.3.5.1 NRHP Eligible Historic Properties Linkages.....	A-15
14		A.3.5.2 NRHP Eligible Historic Properties Metrics	A-16
15		A.3.6 Resources of Traditional Cultural Significance but Not NRHP	
16		Eligible.....	A-16
17		A.3.7 Resources of Traditional Cultural Significance DFCs.....	A-16
18		A.3.8 Resources of Traditional Cultural Significance Linkages	A-17
19		A.3.9 Resources of Traditional Cultural Significance Metrics.....	A-17
20	A.4	Recreation Desired Future Conditions	A-17
21		A.4.1 Recreation DFC Description.....	A-17
22		A.4.2 DFC Background and Legislation	A-17
23		A.4.3 Why the Recreation DFC Is Important	A-18
24		A.4.3.1 Grand Canyon National Park	A-18
25		A.4.3.2 Glen Canyon National Recreation Area.....	A-18
26		A.4.4 Recreation DFCs.....	A-18
27		A.4.4.1 River Recreation in Grand Canyon National Park	A-18
28		A.4.4.2 River Recreation in Glen Canyon National Recreation	
29		Area	A-19
30		A.4.4.3 Blue Ribbon Trout Fishery in Glen Canyon National	
31		Recreation Area.....	A-19
32		A.4.4.4 River Corridor Stewardship.....	A-19
33		A.4.5 Recreation DFC Additional Information	A-20
34		A.4.6 Recreation Linkages.....	A-20
35		A.4.7 Recreation Metrics	A-20
36	A.5	Reference.....	A-21
37			
38	APPENDIX B:	Performance Metrics Used to Evaluate Alternatives	B-1
39			
40	B.1	Aquatic Ecology.....	B-3
41		B.1.1 Humpback Chub	B-3
42		B.1.2 Other Native Fish.....	B-5
43		B.1.3 Trout Fishery.....	B-5
44		B.1.4 Nonnative Aquatic Species	B-6
45	B.2	Archaeological and Cultural Resources	B-7
46	B.3	Hydropower and Energy	B-9

CONTENTS (Cont.)

1
 2
 3
 4 B.4 Natural Processes B-10
 5 B.5 Recreational Experience..... B-10
 6 B.5.1 Grand Canyon Metrics..... B-11
 7 B.5.2 Glen Canyon Metrics B-15
 8 B.6 Riparian Vegetation..... B-16
 9 B.7 Sediment..... B-18
 10 B.8 Tribal Resources..... B-18
 11 B.9 Water Delivery B-24
 12 B.10 References B-24
 13
 14 APPENDIX C: Decision Analysis to Support Development of the Glen Canyon Dam
 15 Long-Term Experimental and Management Plan..... C-1
 16
 17 APPENDIX D: Hydrology Technical Information and Analysis..... D-1
 18
 19 D.1 Analysis Methods..... D-3
 20 D.1.1 Background..... D-3
 21 D.1.2 Initial Conditions D-4
 22 D.1.3 Reservoir Operations D-4
 23 D.1.3.1 Upper Basin Reservoirs above Lake Powell D-4
 24 D.1.3.2 Lake Powell and Lake Mead D-5
 25 D.1.3.3 Lake Mohave and Lake Havasu D-9
 26 D.1.4 Representation of the Different Alternatives in CRSS D-9
 27 D.1.4.1 Experimental Components Modeled in CRSS D-22
 28 D.1.5 Input Hydrology..... D-23
 29 D.1.6 Input Demands D-26
 30 D.1.7 Other Key Assumptions..... D-26
 31 D.2 Supplemental Information on Impact Modeling D-27
 32 D.2.1 Low Summer Flows..... D-27
 33 D.2.2 Modeled Annual Releases Extending Beyond the End of the Water
 34 Year..... D-28
 35 D.2.3 Lake Elevation D-29
 36 D.3 References D-36
 37
 38 APPENDIX E: Sediment Resources Technical Information and Analysis..... E-1
 39
 40 E.1 Introduction E-3
 41 E.1.1 Analysis Period..... E-3
 42 E.1.2 General Scope E-3
 43 E.2 Methods..... E-4
 44 E.2.1 Sand Budget Model..... E-4
 45 E.2.1.1 Model Description E-4
 46 E.2.1.2 Sand Budget Model Modifications..... E-5

CONTENTS (Cont.)

1			
2			
3			
4		E.2.1.3	Modified Sand Budget Model Inputs E-6
5	E.2.2		Sediment Metrics E-8
6		E.2.2.1	Sand Load Index..... E-9
7		E.2.2.2	Standard Deviation of High Flows..... E-9
8		E.2.2.3	Sand Mass Balance Index..... E-10
9	E.3		Results E-10
10		E.3.1	HFES Determined by Alternative..... E-10
11		E.3.2	Metrics E-11
12		E.3.2.1	Sand Load Index..... E-12
13		E.3.2.2	Standard Deviation of High Flows..... E-12
14		E.3.3	Sand Mass Balance Index E-12
15		E.3.4	Alternative Performance under Climate Change Scenarios..... E-13
16		E.3.5	Relative Impacts of Dam Operations and Hydrology on
17			Performance E-13
18	E.4		Lake Deltas E-15
19	E.5		Limitations and Known Issues E-17
20		E.5.1	Geographic Scope E-17
21		E.5.2	Modeling Improvements..... E-17
22	E.6		References E-18
23			
24	APPENDIX F:		Aquatic Resources Technical Information and Analysis..... F-1
25			
26	F.1		Introduction F-3
27	F.2		Aquatic Food Base Assessment F-4
28		F.2.1	Description of the Aquatic Food Base Downstream from Glen
29			Canyon Dam F-4
30		F.2.1.1	The Aquatic Food Base Prior to Construction of Glen
31			Canyon Dam..... F-5
32		F.2.1.2	The Aquatic Food Base of the Colorado River
33			Downstream from Glen Canyon Dam..... F-5
34		F.2.1.3	Influence of New Zealand Mudsail on the Aquatic Food
35			Base F-13
36		F.2.2	Impacts of LTEMP Alternatives on the Aquatic Food Base F-14
37		F.2.2.1	Flow Effects on the Aquatic Food Base..... F-15
38		F.2.2.2	Temperature Effects on the Aquatic Food Base..... F-23
39		F.2.3	Conclusion F-26
40	F.3		Modeling Effects of LTEMP Alternatives on Rainbow Trout and
41			Humpback Chub..... F-28
42		F.3.1	Model Overview F-28
43		F.3.1.1	Glen Canyon Trout Submodel..... F-29
44		F.3.1.2	Trout Movement Submodel..... F-36
45		F.3.1.3	Humpback Chub Population Submodel F-40
46		F.3.2	Results for LTEMP Alternatives F-52

CONTENTS (Cont.)

1
 2
 3
 4 F.3.2.1 Rainbow Trout Performance Measures F-52
 5 F.3.2.2 Humpback Chub Performance Measures F-60
 6 F.4 Modeling the Effects of LTEMP Alternatives on Temperature Suitability F-62
 7 F.4.1 Model Overview F-64
 8 F.4.2 Humpback Chub Aggregations F-67
 9 F.4.2.1 Historic Temperature Suitability for Humpback Chub F-69
 10 F.4.2.2 Results for LTEMP Alternatives F-70
 11 F.4.3 Other Native Fish F-71
 12 F.4.3.1 Historic Temperature Suitability for Native Fish F-73
 13 F.4.3.2 Results for LTEMP Alternatives F-73
 14 F.4.4 Nonnative Fish F-78
 15 F.4.4.1 Historic Temperature Suitability for Nonnative Fish F-79
 16 F.4.4.2 Results for LTEMP Alternatives F-79
 17 F.4.5 Aquatic Parasites F-81
 18 F.4.5.1 Historic Temperature Suitability for Aquatic Parasites F-84
 19 F.4.5.2 Results for LTEMP Alternatives F-86
 20 F.5 References F-90
 21
 22 APPENDIX G: Vegetation Technical Information and Analysis G-1
 23
 24 G.1 Analysis Methods G-3
 25 G.1.1 Old High-Water Zone Analysis G-4
 26 G.1.2 New High-Water Zone G-5
 27 G.1.2.1 Native Cover Metric G-6
 28 G.1.2.2 Native Diversity Metric G-7
 29 G.1.2.3 Native/Nonnative Ratio Metric G-7
 30 G.1.2.4 Arrowweed Metric G-8
 31 G.1.2.5 Overall Score G-8
 32 G.1.3 Wetlands G-9
 33 G.2 Alternative-Specific Impacts G-9
 34 G.2.1 Alternative A (No Action Alternative) G-10
 35 G.2.2 Alternative B G-10
 36 G.2.3 Alternative C G-10
 37 G.2.4 Alternative D (Preferred Alternative) G-11
 38 G.2.5 Alternative E G-11
 39 G.2.6 Alternative F G-11
 40 G.2.7 Alternative G G-12
 41 G.3 Summary G-12
 42 G.4 References G-13
 43
 44 APPENDIX H: Cultural Resources Technical Information and Analysis H-1
 45
 46 H.1 Wind Transport of Sediment H-3

CONTENTS (Cont.)

1		
2		
3		
4	H.1.1	Wind Transport of Sediment—Methods..... H-4
5	H.1.2	Wind Transport of Sediment—Results..... H-5
6	H.2	Flow Effects on Cultural Resources in Glen Canyon..... H-8
7	H.2.1	Flow Effects on Cultural Resources in Glen Canyon—Methods..... H-9
8	H.2.2	Flow Effects on Cultural Resources in Glen Canyon—Results..... H-9
9	H.3	Time Off River..... H-11
10	H.3.1	Time Off River—Methods..... H-12
11	H.3.2	Time Off River—Results..... H-13
12	H.4	References..... H-15
13		
14	APPENDIX I:	Tribal Resources Technical Information and Analysis..... I-1
15		
16	I.1	Quantifiable Measures Used to Assess Impacts on Tribal Resources..... I-4
17	I.1.1	Riparian Diversity..... I-4
18	I.1.2	Wetland Abundance..... I-8
19	I.1.3	Trout Management Flows..... I-10
20	I.1.4	Mechanical Removal of Trout..... I-12
21	I.1.5	Water Levels at Lake Powell..... I-14
22	I.1.6	Access to Resources..... I-17
23	I.2	References..... I-18
24		
25	APPENDIX J:	Recreation, Visitor Use, and Experience Technical Information and
26		Analysis..... J-1
27		
28	J.1	Recreational Experience Metrics..... J-3
29	J.1.1	Grand Canyon Metrics..... J-4
30	J.1.2	Glen Canyon Metrics..... J-4
31	J.2	Metric Definitions, Analysis Methods, and Results..... J-5
32	J.2.1	Camping Area Index..... J-5
33	J.2.1.1	Camping Area Index—Methods..... J-6
34	J.2.1.2	Camping Area Index—Results..... J-7
35	J.2.2	Navigational Risk Index..... J-8
36	J.2.2.1	Navigational Risk Index—Methods..... J-9
37	J.2.2.2	Navigational Risk Index—Results..... J-10
38	J.2.3	Fluctuation Index..... J-11
39	J.2.3.1	Fluctuation Index—Methods..... J-12
40	J.2.3.2	Fluctuation Index—Results..... J-13
41	J.2.4	Time Off River..... J-14
42	J.2.4.1	Time Off River Index—Methods..... J-14
43	J.2.4.2	Time Off River Index—Results..... J-15
44	J.2.5	Glen Canyon Rafting Use..... J-15
45	J.2.5.1	Glen Canyon Rafting Use Metric—Methods..... J-16
46	J.2.5.2	Glen Canyon Rafting Use Metric—Results..... J-17

CONTENTS (Cont.)

1
 2
 3
 4 J.2.6 Glen Canyon Inundation Metric J-18
 5 J.2.6.1 Glen Canyon Inundation Metric—Methods J-19
 6 J.2.6.2 Glen Canyon Inundation Metric—Results J-21
 7 J.3 Lake Powell and Lake Mead Dock Access J-22
 8 J.4 Summary J-25
 9 J.5 References J-25
 10
 11 APPENDIX K Hydropower Systems Technical Information and Analysis..... K-1
 12
 13 K.1 Economic Value of Glen Canyon Dam Powerplant Capacity and Energy
 14 Production K-3
 15 K.1.1 Power Systems Background K-3
 16 K.1.2 Glen Canyon Dam, Reservoir, and Powerplant Background K-5
 17 K.1.3 Power Systems Geographic Scope..... K-8
 18 K.1.3.1 Top Tier: General Western Interconnection Perspective
 19 Modeling K-9
 20 K.1.3.2 Middle Tier: LTF Customer Utility Systems K-11
 21 K.1.3.3 Bottom Tier: Western SLCA/IP Hydropower Resources K-15
 22 K.1.4 Overview of Power Systems Methods..... K-16
 23 K.1.5 Description of Individual Power System Models K-20
 24 K.1.5.1 Colorado River Simulation System Model K-20
 25 K.1.5.2 Representative Trace Tool..... K-21
 26 K.1.5.3 Hydropower Outage Model..... K-21
 27 K.1.5.4 Generation and Transmission Maximization-Lite..... K-21
 28 K.1.5.5 Sand Budget Model K-29
 29 K.1.5.6 Large SLCA/IP Powerplant Spreadsheets..... K-29
 30 K.1.5.7 Small SLCA/IP Powerplant Spreadsheet K-30
 31 K.1.5.8 Loads Shaping Algorithm K-30
 32 K.1.5.9 AURORA K-31
 33 K.1.5.10 LMP Calibration Spreadsheet K-34
 34 K.1.5.11 Firm Capacity Spreadsheet..... K-35
 35 K.1.6 SLCA/IP Market System, Data Sources, and Model K-37
 36 K.1.6.1 Historical Data Sources K-38
 37 K.1.6.2 AURORA Model Dispatch Results for 2013 K-42
 38 K.1.6.3 SLCA/IP Market System Projections..... K-42
 39 K.1.7 Glen Canyon Dam Powerplant Capacity Cost and Benefit
 40 Methodology K-58
 41 K.1.7.1 Treatment of Glen Canyon Dam Capital and Fixed O&M
 42 Costs K-60
 43 K.1.7.2 Western’s SLCA/IP LTF Obligations and Glen Canyon
 44 Dam Replacement Capacity K-60
 45 K.1.7.3 Western SLCA/IP Firm Hydropower Capacity..... K-61

CONTENTS (Cont.)

1
 2
 3
 4 K.1.7.4 Firm Capacity Curves for LTEMP Power Systems
 5 Analyses for the Peak Month of August K-79
 6 K.1.7.5 AURORA Capacity Expansion Reserve Margin Targets
 7 and Capacity Additions K-81
 8 K.1.7.6 Dispatch Performed by AURORA Model Capacity
 9 Expansion Runs K-85
 10 K.1.7.7 Rationale for the Selection of Hydrology Conditions Used
 11 for Capacity Expansion Runs K-89
 12 K.1.8 Glen Canyon Dam Energy Economic Benefits Methodology K-89
 13 K.1.9 Net Present Value Calculations and Study Period Adjustments K-93
 14 K.1.10 Power Systems Results K-95
 15 K.1.10.1 Main Drivers of Differences among Alternatives K-96
 16 K.1.10.2 Capacity Expansion Modeling K-100
 17 K.1.10.3 Economic Impacts K-107
 18 K.1.10.4 Sensitivity of Results to Exceedance Level K-115
 19 K.1.10.5 Sensitivity of Results to Discount Rate K-119
 20 K.1.10.6 Sensitivity of Results to the Base Capacity Expansion Path... K-121
 21 K.1.10.7 Sensitivity of Results to the Assumed Future Hydrological
 22 Conditions K-121
 23 K.1.10.8 Sensitivity of Results to Changes in Ancillary Services K-123
 24 K.1.10.9 Summary of Economic Ranking K-127
 25 K.2 Western’s SLCA/IP Firm Electric Service Rate Impacts K-128
 26 K.2.1 Relationship between the Economic Impacts of LTEMP
 27 Alternatives and Impacts on SLCA/IP FES Rates K-129
 28 K.2.2 Temporal Scope of the Analysis and Input Data K-129
 29 K.2.3 SLCA/IP Rate Setting K-130
 30 K.2.4 Calculation of Net Electrical Energy Expense K-131
 31 K.2.4.1 SLCA/IP Electrical Production K-131
 32 K.2.4.2 Sustainable Hydropower and Available Hydropower
 33 Capacity and Energy K-131
 34 K.2.5 Calculation of Capacity Expenses and Total Net Costs K-135
 35 K.2.6 Western Replacement Resources K-139
 36 K.2.7 Post-2024 Marketing Period K-140
 37 K.2.8 Power Repayment Studies to Determine Rate Impacts K-142
 38 K.2.8.1 PRS Expenses K-142
 39 K.2.8.2 PRS Revenue Distribution K-144
 40 K.2.8.3 The SLCA/IP PRS K-145
 41 K.2.8.4 Standard PRS Rate-Setting Method Versus the Method
 42 Used in This Analysis K-146
 43 K.2.9 Results K-146
 44 K.2.9.1 Pinch-Point Year K-148
 45 K.2.10 Definitions Used in Section K.2 K-149
 46 K.3 Impacts on Retail Electricity Rates K-150

CONTENTS (Cont.)

1
 2
 3
 4 K.3.1 Analysis Approach..... K-150
 5 K.3.1.1 Database of Sales, Rates, and SLCA/IP Allocation for
 6 Retail Utility Systems..... K-152
 7 K.3.1.2 Incorporation of Power Systems Analysis and Capital
 8 Recovery Factors K-155
 9 K.3.1.3 Inflation Rates, Sales Growth, and Interest Rates from EIA... K-157
 10 K.3.1.4 Calculation Process for Computing Rate and Bill Impacts K-157
 11 K.3.2 Results..... K-163
 12 K.3.2.1 Grid Cost Changes Relative to Western Wholesale
 13 Revenues K-163
 14 K.3.2.2 Retail Rate Changes for Individual Systems and SLCA/IP
 15 Power Relative to Total Resources K-164
 16 K.3.2.3 Using Regression Equations to Approximate Retail Rate
 17 Changes for Systems Not Included in the Database..... K-166
 18 K.3.3 Summary of Impacts K-166
 19 K.3.3.1 Average Rate Impacts under LTEMP Alternatives over the
 20 20-Year LTEMP Period K-168
 21 K.3.3.2 Average Year-by-Year Rate Impacts K-171
 22 K.3.3.3 K-Individual System Impacts and Summary
 23 Descriptions of LTEMP Alternatives..... K-173
 24 K.3.4 Impacts on Small Systems K-178
 25 K.3.5 Alternative-Specific Impacts K-181
 26 K.3.5.1 Alternative A K-181
 27 K.3.5.2 Alternative B K-182
 28 K.3.5.3 Alternative C K-183
 29 K.3.5.4 Alternative D K-184
 30 K.3.5.5 Alternative E..... K-184
 31 K.3.5.6 Alternative F..... K-185
 32 K.3.5.7 Alternative G K-185
 33 K.4 Financial Impacts of LTEMP Alternatives on American Indian Tribes K-186
 34 K.4.1 Contractual Requirements for Calculating and Delivering Benefits
 35 to Tribes K-187
 36 K.4.2 Calculation of Tribal Benefit Baseline under Alternative A
 37 (No Action Alternative)..... K-188
 38 K.4.3 Calculation of Change in Tribal Benefit as a Result of LTEMP EIS
 39 Alternatives..... K-189
 40 K.4.4 Impacts on Tribes through a Change in the Retail Rate of the
 41 Electrical Supplier to Tribal Lands..... K-189
 42 K.4.5 Calculation of Tribal Impacts for Tribes That Are Direct SLCA/IP
 43 Recipients..... K-191
 44 K.4.6 Total Impact of LTEMP DEIS Alternatives: Benefit Change and
 45 Rate Effect K-197

CONTENTS (Cont.)

1
 2
 3
 4 K.4.7 Total Impact on Tribes and Tribal Members Versus Retail Rate
 5 Changes to Households..... K-197
 6 K.4.8 Conclusions..... K-198
 7 K.5 Impacts of LTEMP Alternatives on Lake Mead and the Hoover Dam
 8 Powerplant..... K-202
 9 K.5.1 Hoover Methods, Model, and Supporting Data..... K-205
 10 K.5.2 Hoover Monthly Energy Production and Water-to-Power
 11 Conversion..... K-206
 12 K.5.3 Hoover Maximum Physical Output and Firm Capacity..... K-212
 13 K.5.4 Hoover Powerplant Economic Energy Value..... K-214
 14 K.6 References..... K-218
 15 Attachment K.1: Geographic Scope of the Analysis..... K-222
 16 Attachment K.2: AURORA WI Spot Market Energy Prices Adjustments..... K-226
 17 Attachment K.3: Selection of Representative Trace..... K-229
 18 Attachment K.4: Discounting Procedures..... K-247
 19 Attachment K.5: Forced Outage Scenario Generation for Hydroelectric Power
 20 Facilities..... K-250
 21 Attachment K.6: Forecast of Monthly Peak Loads and Energy by SLCA/IP
 22 Long-Term Firm Customer..... K-253
 23 Attachment K.7: Analysis of the Timing of the Peak Load..... K-255
 24 Attachment K.8: Analysis of Capacity Determinations— Comparing Results Using
 25 a Range of Exceedence Levels and Two Summer Peak Months..... K-261
 26 Attachment K.9: Results of a Survey of Electric Utility Integrated Resource Plans..... K-263
 27 Attachment K.10: Indices Used for Converting Dollars from One Year to Another..... K-273
 28 Attachment K.11: Annual SLCA/IP Allocations to American Indian Tribes and
 29 Benefit Information..... K-278
 30 Attachment K.12: SLCA/IP American Indian Tribal Allocations Estimated Total
 31 Electrical Use by Tribe in 1998..... K-284
 32
 33 APPENDIX L: Socioeconomic Technical Information and Analysis..... L-1
 34
 35 L.1 Recreation Economic Analyses..... L-3
 36 L.1.1 Recreation Use Values..... L-3
 37 L.1.1.1 Lake_Full Utility Model..... L-4
 38 L.1.1.2 GCRec_Full Utility Model..... L-5
 39 L.1.2 Recreation Non-Use Values..... L-6
 40 L.1.3 Regional Recreation Economic Impacts..... L-8
 41 L.1.4 Estimates of Recreational Economic Impacts..... L-11
 42 L.2 Regional Electricity Analyses..... L-12
 43 L.2.1 Regional Electricity Price Impacts..... L-12
 44 L.2.2 Regional Electricity Generating Capacity Expansion Impacts..... L-15
 45 L.3 Additional Socioeconomic Data..... L-15
 46 L.3.1 Urban Population in the Six-County Region..... L-15

CONTENTS (Cont.)

1
2
3
4 L.3.2 Urban Income in the Six-County Region..... L-19
5 L.4 References L-20
6
7 APPENDIX M: Air Quality and Climate Change Technical Information and Analysis M-1
8
9 M.1 Analysis Methods..... M-4
10 M.1.1 System Power Generation..... M-4
11 M.1.2 Spot Market..... M-5
12 M.1.3 Generation Type..... M-6
13 M.2 Results M-6
14 M.2.1 SO₂ and NO_x..... M-6
15 M.2.2 Greenhouse Gas Emissions..... M-8
16 M.3 References M-9
17
18 APPENDIX N: Government-to-Government and National Historic Preservation
19 Act Consultation N-1
20
21 N.1 Government-to-Government Consultation..... N-3
22 N.2 Consultation with the State Historic Preservation Office N-27
23 N.3 Reference..... N-30
24 Attachment N.1 N-31
25 Attachment N.2 N-73
26 Attachment N.3 N-135

FIGURES

27
28
29
30
31
32 1-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River
33 between Lake Powell and Lake Mead, and Adjacent Lands..... 1-5
34
35 1-2 Glen Canyon Dam 1-6
36
37 1-3 Map of the Colorado River between Lake Powell and Lake Mead 1-20
38
39 2-1 Mean, Minimum, and Maximum Daily Flows under Alternative A in an
40 8.23-maf Year Based on Values Presented in Table 2-3..... 2-17
41
42 2-2 Simulated Hourly Flows under Alternative A in an 8.23-maf Year..... 2-17
43
44 2-3 Simulated Hourly Flows under Alternative A for a Week in July in an 8.23-maf
45 Year Showing Typically Lower Weekend Flows 2-18
46

FIGURES (Cont.)

1
2
3
4 2-4 Mean, Minimum, and Maximum Daily Flows under Alternative B in an
5 8.23-maf Year Based on Values Presented in Table 2-4..... 2-20
6
7 2-5 Simulated Hourly Flows under Alternative B in an 8.23-maf Year..... 2-21
8
9 2-6 Simulated Hourly Flows under Alternative B for a Week in July in an 8.23-maf
10 Year Showing Typically Lower Weekend Flows 2-21
11
12 2-7 Example Mean, Minimum, and Maximum Daily Flows for a Hydropower
13 Improvement Experiment under Alternative B in an 8.23-maf Year..... 2-23
14
15 2-8 Simulated Hourly Flows for a Hydropower Improvement Experiment under
16 Alternative B in an 8.23-maf Year 2-23
17
18 2-9 Simulated Hourly Flows for a Hydropower Improvement Experiment under
19 Alternative B for a Week in July in an 8.23-maf Year..... 2-24
20
21 2-10 Mean, Minimum, and Maximum Daily Flows under Base Operations of
22 Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-5 2-25
23
24 2-11 Simulated Hourly Flows under Alternative C in an 8.23-maf Year..... 2-27
25
26 2-12 Simulated Hourly Flows under Alternative C for a Week in July in an 8.23-maf
27 Year Showing Typically Lower Weekend Flows 2-27
28
29 2-13 Decision Tree for Sediment-Related Actions under Alternative C 2-28
30
31 2-14 Decision Tree for Humpback Chub-Related Actions under Alternative C..... 2-29
32
33 2-15 Example Implementation of a Two-Cycle TMF in June and July with
34 Resumption of Normal Fluctuations between Cycles and Afterward..... 2-39
35
36 2-16 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer
37 Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in
38 Table 2-6..... 2-41
39
40 2-17 Mean, Minimum, and Maximum Daily Flows under Alternative D in an
41 8.23-maf Year Based on Values Presented in Table 2-8..... 2-44
42
43 2-18 Simulated Hourly Flows under Alternative D in an 8.23-maf Year..... 2-45
44
45 2-19 Simulated Hourly Flows under Alternative D for a Week in July in an 8.23-maf
46 Year Showing Typically Lower Weekend Flows 2-45

FIGURES (Cont.)

1
2
3
4 2-20 Decision Tree for Implementation of Sediment-Related Experimental
5 Treatments under Alternative D 2-53
6
7 2-21 Decision Tree for Implementation of Aquatic Resource-Related Experimental
8 Treatments under Alternative D 2-54
9
10 2-22 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer
11 Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in
12 Table 2-10..... 2-66
13
14 2-23 Mean, Minimum, and Maximum Daily Flows under Alternative E in an
15 8.23-maf Year Based on the Values Presented in Table 2-11 2-71
16
17 2-24 Simulated Hourly Flows under Alternative E in an 8.23-maf Year 2-71
18
19 2-25 Simulated Hourly Flows under Alternative E for a Week in July in an 8.23-maf
20 Year Showing Typically Lower Weekend Flows 2-72
21
22 2-26 Decision Tree for Sediment-Related Actions under Alternative E 2-73
23
24 2-27 Decision Tree for Trout-Related Actions under Alternative E 2-74
25
26 2-28 Mean, Minimum, and Maximum Daily Flows under Base Operations of
27 Alternative F in an 8.23-maf Year Based on the Values Presented in Table 2-12..... 2-79
28
29 2-29 Mean, Minimum, and Maximum Daily Flows under Alternative G in an
30 8.23-maf Year Based on Values Presented in Table 2-13..... 2-80
31
32 3.1-1 LTEMP Project Area and Surrounding Lands 3-2
33
34 3.2-1 Map of Lake Powell and Associated Major Tributaries..... 3-7
35
36 3.2-2 The Pattern of Annual Historic Flows at Lees Ferry..... 3-10
37
38 3.2-3 Map of Lake Mead and Associated Major Tributaries..... 3-11
39
40 3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado
41 River 3-15
42
43 3.2-5 Water Temperature at Lees Ferry 3-16
44
45 3.2-6 Water Temperatures at Four Stations along the Colorado River from Lees Ferry
46 to Diamond Creek, 1995–2014..... 3-19

FIGURES (Cont.)

1
 2
 3
 4 3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek,
 5 1994–2004, as a Function of Mean Weekly Discharge..... 3-20
 6
 7 3.3-1 Geomorphic Features of the Colorado River..... 3-32
 8
 9 3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River 3-34
 10
 11 3.3-3 River Cross Section Depicting Sediment Entrapment and Sandbar Building..... 3-35
 12
 13 3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River..... 3-36
 14
 15 3.3-5 Debris Fans and Variation in Water-Surface Elevation and Channel Width for
 16 Colorado River Flows below Glen Canyon Dam..... 3-38
 17
 18 3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted
 19 in 1973, 1983, and 1991 3-39
 20
 21 3.3-7 Repeated Photography Illustrating Sediment Losses and Sandbar Changes
 22 along the Colorado River..... 3-41
 23
 24 3.3-8 Annual Sediment Contributions from the Paria and Little Colorado River 3-45
 25
 26 3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to
 27 the 2008 HFE..... 3-49
 28
 29 3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size, Duration
 30 and Frequency of HFEs, and Post-HFE Erosion Rates 3-50
 31
 32 3.3-11 Average Campsite Area above the Reference Stage: before, after, and
 33 6 Months following the 2008 HFE..... 3-51
 34
 35 3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the
 36 Hoover Dam in 1935, 1948, 1963, and 2001 3-53
 37
 38 3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and
 39 Nonnative Fishes of the Colorado River System below Glen Canyon Dam..... 3-67
 40
 41 3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen
 42 Canyon Dam and Lake Mead 3-70
 43
 44 3.5-3 Estimated Adult Humpback Chub Abundance from Age-Structured Mark-
 45 Recapture Model Incorporating Uncertainty in Assignment of Age..... 3-71
 46

FIGURES (Cont.)

1
2
3
4 3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the
5 Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver
6 of the Confluence of the Little Colorado and Colorado Rivers, for September,
7 2009 through 2012..... 3-71
8
9 3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence,
10 1995 to Present 3-76
11
12 3.5-6 Mean Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach,
13 1991–2013 3-91
14
15 3.5-7 Mean Electrofishing Catch Rates of Brown Trout in the Colorado River
16 between Lees Ferry and Lake Mead, 2000–2009..... 3-94
17
18 3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam.....3-108
19
20 3.7-1 Riparian Zones Used by Nesting Birds3-119
21
22 3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado
23 River Corridor3-130
24
25 3.8-1 Spencer Steamboat3-141
26
27 3.8-2 A Roaster Site in a Grand Canyon Dune.....3-141
28
29 3.8-3 An Archaic Period Site on the Colorado River in GCNP3-144
30
31 3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA.....3-144
32
33 3.8-5 Puebloan Era Architecture along the Colorado River in GCNP3-145
34
35 3.8-6 Lees Ferry Historic District Located in GCNRA3-147
36
37 3.10-1 Glen Canyon Reach Rainbow Trout.....3-162
38
39 3.10-2 Mean Rainbow Trout Catch Per Unit Effort of Both Boat Anglers and
40 Shore-Line Anglers from Creel Surveys at Lees Ferry3-163
41
42 3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 and 20093-164
43
44 3.10-4 Angler Days in the Glen Canyon Reach from 1965 through 20113-165
45
46 3.10-5 Designated Campsite Areas in the Glen Canyon Reach3-167

FIGURES (Cont.)

1
2
3
4 3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach
5 Ferry Swale Campsite.....3-168
6
7 3.10-7 Pontoon Raft Operated by Colorado River Discovery3-168
8
9 3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month.....3-171
10
11 3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach
12 of GCNP3-172
13
14 3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and 20063-173
15
16 3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between
17 1998 and 20063-174
18
19 3.12-1 Glen Canyon Viewed from the Colorado River3-186
20
21 3.12-2 Horseshoe Bend.....3-186
22
23 3.12-3 Typical View of the Colorado River and Grand Canyon Afforded
24 Recreationists on a River Trip.....3-188
25
26 3.12-4 Colorado River and Granaries at Nankoweap3-188
27
28 3.12-5 Entrance to Havasu Canyon3-189
29
30 3.12-6 Vasey’s Paradise.....3-189
31
32 3.14-1 Minority Population Groups in the 11-County Area3-210
33
34 3.14-2 Low-Income Population Groups in the 11-County Area3-211
35
36 3.15-1 Nonattainment Areas for SO₂, 8-Hour O₃, PM_{2.5}, PM₁₀, and Pb in the
37 11-State Area3-223
38
39 3.15-2 PSD Class I Areas in the 11-State Affected Area3-225
40
41 3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water
42 Supply and.....3-228
43
44 4-1 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations,
45 and Output 4-3
46

FIGURES (Cont.)

1
2
3
4 4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric
5 Values 4-6
6
7 4.2-1 Monthly Releases under Each Alternative in Years with Different Annual
8 Release Volumes 4-20
9
10 4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean,
11 Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for
12 21 Hydrology Scenarios and Three Sediment Scenarios 4-22
13
14 4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the
15 Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum
16 Values for 21 Hydrology Scenarios and Three Sediment Scenarios..... 4-25
17
18 4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives
19 Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and
20 Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios 4-27
21
22 4.2-5 Lake Powell and Lake Mead End of Calendar Year Pool Elevation for 21
23 Hydrology Traces and Seven Alternatives 4-29
24
25 4.2-6 Percentage of Traces below Lake Powell’s Minimum Power Pool and
26 Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces
27 and Seven Alternatives 4-30
28
29 4.2-7 Percentage of Time in Different Operating Tier than Alternative A..... 4-31
30
31 4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under Each of
32 the Alternatives for 21 Hydrologic Traces 4-32
33
34 4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of
35 the Alternatives for 21 Hydrologic Traces 4-33
36
37 4.2-10 Frequency of Occurrence of Annual Releases Extending Beyond the Water
38 Year per 20-Year Trace for Each of the Alternatives..... 4-34
39
40 4.2-11 Comparison of Mean Water Temperatures for Representative Wetter,
41 Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases 4-36
42
43 4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives 4-37
44
45 4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives 4-39
46

FIGURES (Cont.)

1
2
3
4 4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at
5 Lees Ferry 4-43
6
7 4.3-1 Conceptual Depiction of the Sand Load Index..... 4-64
8
9 4.3-2 Conceptual Depiction of the Sand Mass Balance Model 4-65
10
11 4.3-3 Variation in Lake Powell Pool Elevation Relative to Full for 21 Hydrology
12 Traces and Seven Alternatives 4-71
13
14 4.3-4 Variation in Lake Mead Pool Elevation Relative to Full for 21 Hydrology
15 Traces and Seven Alternatives 4-72
16
17 4.3-5 Number and Type of HFES Expected to Occur during the 20-Year LTEMP
18 Period under the Seven Alternatives 4-73
19
20 4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven
21 Alternatives..... 4-74
22
23 4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the
24 Seven Alternatives..... 4-75
25
26 4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats,
27 and Ecological Resources in the Colorado River Ecosystem..... 4-85
28
29 4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the
30 Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP
31 Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile,
32 Minimum, and Maximum Values for 21 Hydrology Scenarios4-115
33
34 4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the
35 Marble Canyon Reach from the Glen Canyon Reach during the 20-Year
36 LTEMP Period under the LTEMP Alternatives4-117
37
38 4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach
39 Exceeding 16 in. Total Length during 20-Year Simulation Periods under the
40 LTEMP Alternatives4-118
41
42 4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout
43 under LTEMP Alternatives at Four Locations Downstream of Glen Canyon
44 Dam4-119
45

FIGURES (Cont.)

1
2
3
4 4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish
5 under LTEMP Alternatives at Four Locations Downstream of Glen Canyon
6 Dam4-120
7
8 4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under
9 LTEMP Alternatives at Reported Aggregation Locations and Combined
10 Temperature Suitability for RM 157 and RM 213 Locations4-122
11
12 4.5-7 Mean Modeled Total Length Attained by December 31 for YOY Humpback
13 Chub Based on Predicted Mainstem Water Temperatures at the Little Colorado
14 River Confluence and at Pumpkin Spring under Each Alternative4-123
15
16 4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year
17 LTEMP Period under LTEMP Alternatives4-124
18
19 4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish under LTEMP
20 Alternatives at Four Locations Downstream of Glen Canyon Dam4-127
21
22 4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP
23 Alternatives for Aquatic Fish Parasites at Four Locations Downstream of Glen
24 Canyon Dam4-128
25
26 4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon
27 Dam4-157
28
29 4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as
30 Predicted by a Vegetation Model4-163
31
32 4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as
33 Predicted by a Vegetation Model4-164
34
35 4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a
36 Vegetation Model4-173
37
38 4.8-1 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP
39 Alternatives4-224
40
41 4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives4-226
42
43 4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP
44 Alternatives4-263
45
46

FIGURES (Cont.)

1
 2
 3
 4 4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP DEIS4-298
 5
 6 4.13-2 Average Daily Glen Canyon Dam Generation under Representative
 7 Hydrological Conditions under LTEMP Alternatives.....4-311
 8
 9 4.13-3 Total NPV of Hoover Powerplant Benefits over a 20-Year Period under
 10 LTEMP Alternatives4-317
 11
 12 4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period.....4-363
 13
 14 4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions
 15 under Climate Change4-371
 16
 17 4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile,
 18 25th Percentile, Minimum, and Maximum Values for 112 Climate-Change
 19 Inflow Traces and 21 Historic Inflow Traces.....4-372
 20
 21 4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean
 22 Daily Flow and Mean Daily Change in Flow by Month for LTEMP
 23 Alternatives.....4-376
 24
 25 D-1 Operating Tiers as Specified by the 2007 Interim Guidelines for the Operations
 26 of Lake Powell and Lake Mead..... D-7
 27
 28 D-2 Monthly Releases in kaf for Each Alternative in an 8.23-maf Release Year..... D-21
 29
 30 D-3 Locations of CRSS 29 Natural Flow Nodes..... D-24
 31
 32 D-4 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for
 33 Lake Powell Annual Inflow, Lake Powell Water Year Release Volume and
 34 Lake Powell Monthly Release Volume..... D-25
 35
 36 D-5 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for
 37 Lake Powell End of December Water Elevations at the 10th, 50th, and
 38 90th Percentiles D-25
 39
 40 D-6 Occurrences of Low Summer Flows in Applicable Alternatives..... D-28
 41
 42 D-7 Frequency of Occurrence of Modeled Annual Releases Extending beyond the
 43 End of the Water Year per 20-Year Trace for Each of the Alternatives D-29
 44
 45 D-8 Median Volume of Modeled Annual Releases Extending beyond the End of the
 46 Water Year Releases by Trace for Each of the Alternatives D-30

FIGURES (Cont.)

1
2
3
4 D-9 Lake Powell and Lake Mead End-of-December Pool Elevation for
5 21 Hydrology Traces under Alternatives A and B D-30
6
7 D-10 Lake Powell and Lake Mead End-of-December Pool Elevation for
8 21 Hydrology Traces under Alternatives A and C D-31
9
10 D-11 Lake Powell and Lake Mead End-of-December Pool Elevation for
11 21 Hydrology Traces under Alternatives A and D D-31
12
13 D-12 Lake Powell and Lake Mead End-of-December Year Pool Elevation for
14 21 Hydrology Traces under Alternatives A and E D-32
15
16 D-13 Lake Powell and Lake Mead End-of-December Pool Elevation for
17 21 Hydrology Traces under Alternatives A and F D-32
18
19 D-14 Lake Powell and Lake Mead End-of-December Pool Elevation for
20 21 Hydrology Traces under Alternatives A and G D-33
21
22 D-15 Percent of Traces below Lake Powell’s Minimum Power Pool and Percent of
23 Traces with a Lower Basin Shortage for 21 Hydrology Traces under
24 Alternatives A and B D-33
25
26 D-16 Percent of Traces below Lake Powell’s Minimum Power Pool and Percent of
27 Traces with a Lower Basin Shortage for 21 Hydrology Traces under
28 Alternatives A and C D-34
29
30 D-17 Percent of Traces below Lake Powell’s Minimum Power Pool and Percent of
31 Traces with a Lower Basin Shortage for 21 Hydrology Traces under
32 Alternatives A and D D-34
33
34 D-18 Percent of Traces below Lake Powell’s Minimum Power Pool and Percent of
35 Traces with a Lower Basin Shortage for 21 Hydrology Traces under
36 Alternatives A and E D-35
37
38 D-19 Percent of Traces below Lake Powell’s Minimum Power Pool and Percent of
39 Traces with a Lower Basin Shortage for 21 Hydrology Traces under
40 Alternatives A and F D-35
41
42 D-20 Percent of Traces below Lake Powell’s Minimum Power Pool and Percent of
43 Traces with a Lower Basin Shortage for 21 Hydrology Traces under
44 Alternatives A and G D-36
45
46

FIGURES (Cont.)

1
2
3
4 E-1 Comparison of Calendar, Water, and Sediment Years..... E-20
5
6 E-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations,
7 and Output E-21
8
9 E-3 Conceptual Schematic of the Sand Budget Model E-22
10
11 E-4 Historical Paria Sediment Load per Accounting Period and the 20.5-year Load
12 for the Trace That Begins in Each Fall Accounting Period..... E-22
13
14 E-5 Sediment Traces s1, s2, and s3 for the Paria River Used in the Modeling to
15 Account for Uncertainty in Future Delivery E-23
16
17 E-6 Little Colorado River Sediment Traces for s1, s2, and s3 Used in the Modeling
18 to Account for Uncertainty in Future Delivery E-23
19
20 E-7 Conceptual Representation of the Sand Mass Balance Index E-24
21
22 E-8 Average Sediment and Hydrology Triggered HFE Count by Type for Each
23 Long-Term Strategy E-24
24
25 E-9 Average HFE Count for Sediment Traces s1, s2, s3 for Each Long-Term
26 Strategy E-25
27
28 E-10 Definition of the Statistics Represented by the Box and Whisker Plots Used in
29 This Analysis E-25
30
31 E-11 Sand Load Index Statistics from 63 Simulations for Each Long-Term Strategy E-26
32
33 E-12 Standard Deviation of High Flows Statistics from 63 Simulations for Each
34 Long-Term Strategy E-26
35
36 E-13 Correlation between SDHF and SLI..... E-27
37
38 E-14 Sand Mass Balance Index Statistics from 63 Simulations for Each Long-Term
39 Strategy E-27
40
41 E-15 Correlation between SMBI and SLI E-28
42
43 E-16 Sand Load Index for Long-Term Strategies Using Climate Change Weights E-28
44
45 E-17 Comparison of the Sand Load Index between Climate Change and Historical
46 Weights..... E-29

FIGURES (Cont.)

1
2
3
4 E-18 Standard Deviation of High Flows Using Climate Change Weights E-29
5
6 E-19 Comparison of the Standard Deviation of High Flows between Climate Change
7 and Historical Weights E-30
8
9 E-20 Sand Mass Balance Index Using Climate Change Weights E-30
10
11 E-21 Comparison of the Sand Mass Balance Index between Climate Change and
12 Historical Weights E-31
13
14 E-22 Comparison of Long-Term Strategies C1 and C2 for Hydrology Trace 1,
15 Sediment Trace 3 E-31
16
17 E-23 SMBI for Alternative E Plotted against Alternative C E-32
18
19 E-24 SLI for Alternative E Plotted against Alternative C E-32
20
21 E-25 Load-Following Curtailment Effects on SLI and SMBI E-33
22
23 E-26 Low Summer Flows for WY 2014, Hydrology Trace 1, Sediment Trace 1 E-34
24
25 E-27 Hydrology Impacts on the Sand Load Index E-35
26
27 E-28 Hydrology Impacts on the Sand Mass Balance Index E-35
28
29 E-29 Conceptual Diagram of Water Surface Elevation Affecting Delta Location E-36
30
31 E-30 Historical Cumulative Sand Load Leaving Marble Canyon and Reaching the
32 Gage above Diamond Creek E-36
33
34 E-31 Hydrology Impacts of Lake Powell Pool Elevations by Month across
35 Alternatives E-37
36
37 E-32 Hydrology Impacts of Lake Mead Pool Elevations by Month across
38 Alternatives E-37
39
40 F-1 Fit of Regressions Predicting the Log of Recruitment of Rainbow Trout in the
41 Glen Canyon Reach Estimated by the Korman et al. (2012) Stock Synthesis
42 Model as a Function of the Annual Release Volume from Glen Canyon Dam,
43 the Range of Mean Daily Flows during May–August, and the Maximum Flow
44 Each Year F-31
45

FIGURES (Cont.)

1
2
3
4 F-2 Relationship between Annual Estimates of the Asymptotic Length of Rainbow
5 Trout in Lees Ferry Predicted by the Stock Synthesis Model as a Function of
6 the Estimated Abundance for Fish >150 mm Each Year F-32
7
8 F-3 The Relationship between Annual Recruitment of Rainbow Trout in Lees Ferry
9 Estimated by the Korman et al. (2012) Stock Synthesis Model and the Number
10 of Trout That Emigrate from Lees Ferry into Marble Canyon the Following
11 Year F-35
12
13 F-4 Fit of the Glen Canyon Rainbow Trout Simulation Model to Predictions of
14 Recruitment, Asymptotic Length, and the Number of Out-migrants Predicted
15 by the Korman et al. (2012) Stock Synthesis Model..... F-37
16
17 F-5 Predicted and Observed Annual Catch of Rainbow Trout by Year and River
18 Reach F-41
19
20 F-6 Best-Fitting Distributions Describing Monthly Movement of Rainbow Trout in
21 Marble Canyon Assuming Either a Normal or Cauchy Distribution F-43
22
23 F-7 Visual Summary of Humpback Chub Population Model Structure F-44
24
25 F-8 Modeled Effects of Trout Abundance and Temperature on Humpback Chub
26 Survival and Growth..... F-48
27
28 F-9 Simulated Adult Abundances from Backcasted Model Compared to Patterns
29 Reported in Coggins and Walters (2009) F-51
30
31 F-10 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the
32 Glen Canyon Reach during the 20-year LTEMP Period under LTEMP
33 Alternatives and Long-Term Strategies..... F-54
34
35 F-11 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach
36 Exceeding 16 in. Total Length during the 20-year LTEMP Period under the
37 LTEMP Alternatives and Long-Term Strategies F-55
38
39 F-12 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen
40 Canyon Reach and the Mean Number of Rainbow Trout Exceeding 16 in. Total
41 Length during the 20-year LTEMP Period under the LTEMP Alternatives and
42 Long-Term Strategies..... F-56
43
44 F-13 Modeled Mean Annual Angler Catch Rate for Rainbow Trout in the Glen
45 Canyon Reach during the 20-year LTEMP Period under the LTEMP
46 Alternatives and Long-Term Strategies..... F-57

FIGURES (Cont.)

1
2
3
4 F-14 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen
5 Canyon Reach and Mean Angler Catch Rates during the 20-year LTEMP
6 Period under the LTEMP Alternatives and Long-Term Strategies F-58
7
8 F-15 Modeled Annual Average Number of Rainbow Trout Emigrating into the
9 Marble Canyon Reach from the Glen Canyon Reach during the 20-year
10 LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-59
11
12 F-16 Modeled Frequency of Triggered Mechanical Removal for Rainbow Trout in
13 the Little Colorado River Reach during the 20-year LTEMP Period under the
14 LTEMP Alternatives and Long-Term Strategies F-61
15
16 F-17 Modeled Minimum Population Size for Humpback Chub during the 20-year
17 LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-62
18
19 F-18 Relationship between Modeled Mean Numbers of Rainbow Trout Out-migrants
20 from the Glen Canyon Reach and the Modeled Mean Minimum Abundance of
21 Adult Humpback Chub during the 20-year LTEMP Period under the LTEMP
22 Alternatives and Long-Term Strategies F-63
23
24 F-19 Suitability for Spawning, Egg Incubation, and Growth of Humpback Chub as a
25 Function of Water Temperature F-68
26
27 F-20 Months for Which Annual Temperature Suitability for Specific Life History
28 Aspects of Humpback Chub Were Calculated F-68
29
30 F-21 Modeled Historic Water Temperatures in the Colorado River at Humpback
31 Chub Aggregation Locations, Water Years 1990–2012 F-70
32
33 F-22 Output from the Temperature Suitability Model for Humpback Chub
34 Aggregation Locations Based on Modeled Water Temperatures for Water
35 Years 1990–2012 F-71
36
37 F-23 Mainstem Temperature Suitability for Humpback Chub Aggregation Locations
38 under LTEMP Alternatives and Long-Term Strategies F-72
39
40 F-24 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth
41 of Native Fish Species F-74
42
43 F-25 Months for Which Temperature Suitability for Specific Life History Aspects
44 Were Considered for Native Fish Species F-74
45

FIGURES (Cont.)

1
2
3
4 F-26 Modeled Historic Water Temperatures in the Colorado River Downstream of
5 Glen Canyon Dam, Water Years 1990–2012 F-75
6
7 F-27 Annual Temperature Suitability Scores for Growth, Spawning, and Egg
8 Incubation of Native Fish Species at RM 225 Based on Modeled Water
9 Temperatures for Water Years 1990–2012 F-76
10
11 F-28 Annual Temperature Suitability Scores for Native Fish by Assessment Location
12 Based on Modeled Water Temperatures for Water Years 1990–2012..... F-77
13
14 F-29 Mean Annual Overall Temperature Suitability for Native Fish by Assessment
15 Location Based on Modeled Water Temperatures for Water Years 1990–2012 F-77
16
17 F-30 Mean Annual Mainstem Temperature Suitability for Native Fish under LTEMP
18 Alternatives and Long-Term Strategies at RM 61, RM 157, and RM 225, and
19 Overall Mean for RM 61–225 F-78
20
21 F-31 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth
22 of Nonnative Fish Species F-80
23
24 F-32 Months during Which Temperature Suitability for Specific Life History
25 Aspects Were Calculated for Nonnative Fish Species F-81
26
27 F-33 Annual Temperature Suitability Scores for Spawning, Incubation, and Growth
28 of Nonnative Fish Species at RM 225 Based on Modeled Temperatures for
29 Water Years 1990 to 2012 F-82
30
31 F-34 Mean Annual Temperature Suitability Scores for Nonnative Fish Species and
32 for Temperature Groups by River Location Based on Modeled Water
33 Temperatures for Water Years 1990–2012 F-83
34
35 F-35 Mean Annual Overall Temperature Suitability Scores for Coldwater and
36 Warmwater Nonnative Fish Species Groups Based on Modeled Historic
37 Temperatures for Water Years 1990–2012 F-83
38
39 F-36 Mean Annual Mainstem Temperature Suitability for Coldwater Nonnative Fish
40 under LTEMP Alternatives and Long-Term Strategies at RM –15 RM 61, RM
41 157, and RM 225 F-84
42
43 F-37 Mean Annual Mainstem Temperature Suitability for Warmwater Nonnative
44 Fish under LTEMP Alternatives and Long-Term Strategies at RM 0, RM 61,
45 RM 157, and RM 225 F-85
46

FIGURES (Cont.)

1
2
3
4 F-38 Suitability of Various Water Temperatures for Host Activity and Infestation
5 Rates of Parasite Species F-86
6
7 F-39 Annual Temperature Suitability Scores for Parasite Species at RM 225 F-87
8
9 F-40 Mean Annual Temperature Suitability Scores for Parasite Species by River
10 Location Based on Modeled Water Temperatures for Water Years 1990–2012 F-87
11
12 F-41 Overall Means of Annual Suitability Scores for Parasite Species Across All
13 River Locations during the 1990–2012 Water Years F-88
14
15 F-42 Overall Modeled Mean Annual Temperature Suitability under LTEMP
16 Alternatives and Long-Term Strategies for Aquatic Fish Parasites at Four
17 Locations Downstream of Glen Canyon Dam..... F-89
18
19 G-1 Native Cover Metric for the LTEMP Alternatives and Associated Long-Term
20 Strategies G-45
21
22 G-2 Native Cover Metric under Climate Change for the LTEMP Alternatives and
23 Associated Long-Term Strategies G-45
24
25 G-3 Native Diversity Metric for the LTEMP Alternatives and Associated Long-
26 Term Strategies..... G-46
27
28 G-4 Native Diversity Metric under Climate Change for the LTEMP Alternatives
29 (Letters) and Associated Long-Term Strategies..... G-46
30
31 G-5 Native/Nonnative Ratio Metric for the LTEMP Alternatives and Associated
32 Long-Term Strategies..... G-47
33
34 G-6 Native/Nonnative Ratio Metric under Climate Change for the LTEMP
35 Alternatives and Associated Long-Term Strategies G-47
36
37 G-7 Arrowweed Metric for the LTEMP Alternatives and Associated Long-Term
38 Strategies G-48
39 G-8 Arrowweed Metric under Climate Change for the LTEMP Alternatives and
40 Associated Long-Term Strategies G-48
41
42 G-9 Overall Combined Score for the LTEMP Alternatives and Associated Long-
43 Term Strategies..... G-49
44
45 G-10 Overall Combined Score under Climate Change for the LTEMP Alternatives
46 and Associated Long-Term Strategies..... G-49

FIGURES (Cont.)

1
 2
 3
 4 G-11 Relative Change in Wetland Cover for the LTEMP Alternatives and Associated
 5 Long-Term Strategies..... G-50
 6
 7 G-12 Relative Change in Wetland Cover under Climate Change for the LTEMP
 8 Alternatives and Associated Long-Term Strategies G-50
 9
 10 H-1 Wind Transport of Sediment Index Values for the LTEMP Alternatives and
 11 Associated Long-Term Strategies H-6
 12
 13 H-2 Average Number of HFEs in the 20-Year LTEMP Period H-7
 14
 15 H-3 Daily Maximum Discharge in a Typical 8.23-maf Water Volume Release Year
 16 from the Glen Canyon Dam during the Windy Season of March–June..... H-8
 17
 18 H-4 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP
 19 Alternatives and Long-Term Strategies..... H-10
 20
 21 H-5 Average Number of Days of an HFE Event per Year H-11
 22
 23 H-6 Modeled Glen Canyon Dam Discharge for the Same Year H-12
 24
 25 H-7 Time Off River Index Values for All LTEMP Alternatives and Associated
 26 Long-Term Strategies..... H-14
 27
 28 H-8 Daily Average Discharge for Representative Long-Term LTEMP Strategies..... H-15
 29
 30 I-1 Riparian Diversity for the LTEMP Alternatives and Associated Long-Term
 31 Strategies I-6
 32
 33 I-2 Riparian Diversity under Climate Change Assumptions for the LTEMP
 34 Alternatives and Associated Long-Term Strategies I-7
 35
 36 I-3 Wetland Abundance for the LTEMP Alternatives and Associated Long-Term
 37 Strategies I-9
 38
 39 I-4 Wetland Abundance under Climate Change Assumptions for the LTEMP
 40 Alternatives and Associated Long-Term Strategies I-10
 41
 42 I-5 Frequency of Trout Management Flows for the LTEMP Alternatives and
 43 Associated Long-Term Strategies I-12
 44
 45 I-6 Frequency of Trout Management Flows under Climate Change Assumptions
 46 for the LTEMP Alternatives and Associated Long-Term Strategies I-13

FIGURES (Cont.)

1
2
3
4 I-7 Frequency of Mechanical Removal for the LTEMP Alternatives and Associated
5 Long-Term Strategies..... I-14
6
7 I-8 Frequency of Mechanical Removal under Climate Change Assumptions for the
8 LTEMP Alternatives and Associated Long-Term Strategies..... I-15
9
10 I-9 Lake Powell Water Levels for the LTEMP Alternatives and Associated Long-
11 Term Strategies..... I-16
12
13 I-10 Lake Powell Water Levels under Climate Change Assumptions for the LTEMP
14 Alternatives and Associated Long-Term Strategies..... I-17
15
16 J-1 Camping Area Index for LTEMP Long-Term Strategies..... J-8
17
18 J-2 Sand Load Index for LTEMP Long-Term Strategies..... J-9
19
20 J-3 Navigational Risk Index Values for the LTEMP Long-Term Strategies..... J-11
21
22 J-4 Fluctuation Index for LTEMP Long-Term Strategies..... J-13
23
24 J-5 Time Off River Index for LTEMP Long-Term Strategies..... J-15
25
26 J-6 Average Daily Discharge for All Modeled Traces and Years under LTEMP
27 Alternatives..... J-16
28
29 J-7 Glen Canyon Rafting Metric for All LTEMP Long-Term Strategies..... J-18
30
31 J-8 Average Number of HFES in the 20-Year LTEMP Period for LTEMP
32 Long-Term Strategies..... J-19
33
34 J-9 Glen Canyon Inundation Metric for All LTEMP Long-Term Strategies..... J-21
35
36 J-10 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL
37 for the Summer Season..... J-23
38
39 J-11 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL
40 for the Fall and Spring Seasons..... J-23
41
42 J-12 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL
43 for the Summer Season..... J-24
44
45 J-13 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL
46 for the Fall and Spring Seasons..... J-24

FIGURES (Cont.)

1
2
3
4 K.1-1 Network Topology Used by the AURORA Western Interconnection Model..... K-10
5
6 K.1-2 SLCA/IP LTF Customer Capacity Ownership Percentages..... K-12
7
8 K.1-3 Simplified Network Topology of the SLCA/IP Market System K-13
9
10 K.1-4 Percent of SLCA/IP Federal Hydropower Nameplate Capacity by Facility..... K-16
11
12 K.1-5 Flow Diagram of the Power Systems Methodology Used in the LTEMP DEIS K-18
13
14 K.1-6 Illustration of a Typical GTMax-Lite Result for a 24-Hour Period K-24
15
16 K.1-7 GTMax-Lite Network Topology for the Large SLCA/IP Hydropower
17 Resources Other Than Glen Canyon Dam K-26
18
19 K.1-8 Illustration of Temporal Modeling Method Used in the GTMax-Lite Five Large
20 SLCA/IP Plant Configuration..... K-28
21
22 K.1-9 Example of the Load Scaling Algorithm LDC..... K-31
23
24 K.1-10 Example of the Load Scaling Algorithm Chronological Hourly Loads..... K-32
25
26 K.1-11 Projected Annual Average Calibrated AURORA LMPs at the Palo Verde
27 Market Hub..... K-36
28
29 K.1-12 Historical Palo Verde On- and Off-Peak Electricity Prices Compared to Natural
30 Gas Prices K-36
31
32 K.1-13 2014 AEO Projected Delivered Utility Natural Gas Prices..... K-38
33
34 K.1-14 Comparison of Modeled and Actual Annual Aggregated Generation Levels for
35 Natural Gas, Coal, and Nuclear Powerplants under the No Action Alternative K-43
36
37 K.1-15 Total Non-coincidental Peak Loads for the SLCA/IP Market System..... K-49
38
39 K.1-16 Total Monthly Loads for the SLCA/IP Market System K-49
40
41 K.1-17 Projected 2014 AEO Natural Gas Prices at the Henry Hub K-55
42
43 K.1-18 2014 AEO Electricity Market Module Regions and the Mapping of States to
44 Regions K-56
45
46 K.1-19 Projected AEO 2014 Coal Prices by Electricity Market Module Region K-58

FIGURES (Cont.)

1
2
3
4 K.1-20 Western SLCA/IP Hydropower Powerplants K-62
5
6 K.1-21 SLCA/IP Federal Hydropower Capacity Uses and Variability Factors K-63
7
8 K.1-22 Reductions in Operating Range when Providing Ancillary Services..... K-65
9
10 K.1-23 Illustration of the Trapezoidal Method Used to Compute Capacity at Flaming
11 Gorge Dam K-71
12
13 K.1-24 Illustration of Ramping Time Increase as a Function of Increasing Water
14 Volumes at Flaming Gorge Dam..... K-72
15
16 K.1-25 Capacity Values at Flaming Gorge Dam Calculated over a Wide Range of
17 Daily Water Releases Using the Trapezoidal Method K-73
18
19 K.1-26 Average Historical Non-coincidental Annual Peak Loads for the Eight Large
20 Customers and Percentages Relative to the Total K-75
21
22 K.1-27 Historical Coincidental Annual and Average Peak Loads for the Eight Large
23 Customers during the CY 2006 through CY 2009 Time Period K-76
24
25 K.1-28 Historical Coincidental Annual and Average Peak Loads for Six Large
26 Customers during the CY 2010 through CY 2012 Time Period K-76
27
28 K.1-29 SLCA/IP Models Used for Estimating SHP Capacity K-78
29
30 K.1-30 Historical SHP Capacity Obligation and Western Estimated Risk Level in July K-79
31
32 K.1-31 Historical SHP Capacity Obligation and Western Estimated Risk Level in
33 August..... K-80
34
35 K.1-32 Comparison of Firm Marketable Capacity Determinations across Alternatives,
36 Exceedance Levels, and Summer Peak Months K-80
37
38 K.1-33 Timing of Capacity Additions in AURORA K-83
39
40 K.1-34 Annual Average Hydropower Generation for the Glen Canyon Dam Powerplant
41 and the Aggregate Generation for all other SLCA/IP Resources..... K-87
42
43 K.1-35 Average Daily Glen Canyon Dam Powerplant Hydropower Generations by
44 Month Based on the Average of All 21 CRSS/SBM Hydrology Traces K-88
45

FIGURES (Cont.)

1
2
3
4 K.1-36 Average Annual Glen Canyon Dam Powerplant Generation for the
5 Representative CRSS/SBM Hydrology Trace..... K-91
6
7 K.1-37 Representative Trace Average Daily Glen Canyon Dam Powerplant
8 Generations by Month K-92
9
10 K.1-38 Average Daily Generation by Month for Each Alternative..... K-96
11
12 K.1-39 Palo Verde Average Daily Electricity Market Price Statistics by Month during
13 the 20-Year LTEMP Period..... K-97
14
15 K.1-40 Typical Hourly Winter/Summer Price Patterns in the Western United States K-98
16
17 K.1-41 Average Number of HFEs by Alternative for All 21 Hydrology Traces of
18 Sediment Trace 2 K-99
19
20 K.1-42 Average Amount of Water Spilled by Alternative for All 21 Hydrology Traces
21 of Sediment Trace 2..... K-99
22
23 K.1-43 Average Annual Number of Hours the Lake Powell Elevation Is below the
24 Penstock Intake by Alternative for All 21 Hydrology Traces of Sediment
25 Trace 2 K-100
26
27 K.1-44 2014 Annual Energy Outlook Projections of Capacity Additions in the Western
28 Interconnection over the LTEMP Period K-103
29
30 K.1-45 Cumulative Capacity Additions for Alternative A K-105
31
32 K.1-46 Cost Difference of Alternatives Compared to Alternative A at 50% Exceedance
33 Level and 3.375% Discount Rate K-117
34
35 K.1-47 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance
36 Level and 3.375% Discount Rate K-118
37
38 K.1-48 Cost Difference of Alternatives Compared to Alternative A at 99% Exceedance
39 Level and 3.375% Discount Rate K-118
40
41 K.1-49 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance
42 Level and 1.4% Discount Rate K-120
43
44 K.1-50 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance
45 Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity
46 Additions Are Advanced Combustion Turbines K-122

FIGURES (Cont.)

1
2
3
4 K.1-51 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance
5 Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity
6 Additions Are Advanced Combined CycleK-123
7
8 K.1-52 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance
9 Level and 3.375% Discount Rate Assuming Average Hydropower Conditions.....K-124
10
11 K.2-1 Determination of Energy Hourly Expense or RevenueK-136
12
13 K.2-2 Determination of Total Net Expense or Revenue by Year for Each AlternativeK-138
14
15 K.3-1 Flowchart Diagram of Rate Impact Analysis ProcessK-152
16
17 K.3-2 Projected Carrying Charge Rates Used in Rate Impact Analysis.....K-157
18
19 K.3-3 Flowchart Diagram of Allocation ProcessK-158
20
21 K.3-4 Load Factors of SLCA/IP Power.....K-161
22
23 K.3-5 Scatter Plot of Preference Ratio and Annual Retail Sales.....K-165
24
25 K.3-6 Scatter Plots of Percent Retail Rate Change and the Preference RatioK-167
26
27 K.3-7 Retail Rate Distribution under Alternative A.....K-168
28
29 K.3-8 Monthly Residential Bill Distribution under Alternative AK-169
30
31 K.3-9 Average Retail Rate Impacts under LTEMP Alternatives Relative to
32 Alternative AK-170
33
34 K.3-10 Average Residential Bill Impacts under LTEMP alternatives Relative to
35 Alternative AK-170
36
37 K.3-11 Average Retail Percent Revenue Increase Relative to Alternative AK-171
38
39 K.3-12 Average Monthly Residential Bill Changes Relative to Alternative A.....K-172
40
41 K.3-13 Retail Rates under Alternative A.....K-183
42
43 K.4-1 Calculation of Change in Tribal Benefit Resulting from LTEMP DEIS
44 Alternatives.....K-190
45

FIGURES (Cont.)

1
2
3
4 K.4-2 Financial Impacts under Alternative B Relative to Alternative A for Tribal and
5 Non-Tribal EntitiesK-199
6
7 K.4-3 Financial Impacts under Alternative C Relative to Alternative A for Tribal and
8 Non-Tribal EntitiesK-199
9
10 K.4-4 Financial Impacts under Alternative D Relative to Alternative A for Tribal and
11 Non-Tribal EntitiesK-200
12
13 K.4-5 Financial Impacts under Alternative E Relative to Alternative A for Tribal and
14 Non-Tribal EntitiesK-200
15
16 K.4-6 Financial Impacts under Alternative F Relative to Alternative A for Tribal and
17 Non-Tribal EntitiesK-201
18
19 K.4-7 Financial Impacts under Alternative G Relative to Alternative A for Tribal and
20 Non-Tribal EntitiesK-201
21
22 K.5-1 Comparison of Alternative A and Alternative F Lake Powell Average Monthly
23 Water Releases over the 20-Year Study Period and 21 Hydrology Traces.....K-203
24
25 K.5-2 Impact of Changed Lake Powell Month Water Release Volumes on Mead
26 Average EOM Pool ElevationsK-203
27
28 K.5-3 Lake Mead Storage Elevation Curve and Change in Elevation as a Function of
29 Lake Mead Water StorageK-204
30
31 K.5-4 Results of Water-to-Power Conversion Factor Back-casting Exercise.....K-207
32
33 K.5-5 Average Monthly Water-to-Power Conversion Factor and Energy Production
34 per ac-ft of Total Mead Reservoir Release.....K-209
35
36 K.5-6 Average Monthly Turbine and Bypass Water ReleasesK-209
37
38 K.5-7 Average Monthly Change in Turbine Water ReleasesK-210
39
40 K.5-8 Monthly Probability of a Water Bypass Event Due to a Low Mead Pool
41 Elevation.....K-210
42
43 K.5-9 Average Monthly Generation per ac-ft of Total Mead Reservoir Release for All
44 Power Systems Primary LTEMP DEIS AlternativesK-211
45

FIGURES (Cont.)

1
2
3
4 K.5-10 Alternative F Changes in Monthly Hoover Powerplant Turbine Water Releases
5 under Hydrology Trace 8.....K-212
6
7 K.5-11 Average Monthly Hoover Powerplant Generation for All Power Systems
8 Primary LTEMP DEIS Alternatives.....K-213
9
10 K.5-12 Hoover Powerplant Maximum Physical Output as a Function of Lake Mead
11 Pool ElevationK-213
12
13 K.5-13 Hoover Powerplant Maximum Output Exceedance Curve for the Month of
14 August.....K-214
15
16 K.5-14 Average Monthly Change in Hoover Powerplant Energy Economic Value
17 Relative to Alternative A for All Power Systems Primary LTEMP SEIS
18 Alternatives.....K-215
19
20 K.5-15 NPV of Hoover Powerplant Benefits Relative to Alternative A Resulting from
21 LTEMP AlternativesK-216
22
23 K.5-16 NPV Comparison of SLCA/IP Costs and Hoover Powerplant Benefits
24 Resulting from Changed Operating Criteria at Glen Canyon Dam.....K-217
25
26 K.5-17 NPV Comparison of SLCA/IP Costs and Hoover Powerplant Benefits
27 Resulting from LTEMP AlternativesK-217
28
29 L-1 Elements of the Lake_Full Utility Model..... L-5
30
31 L-2 Elements of the GCRec_Full Utility Model..... L-6
32
33 L-3 Elements of the Regional Recreation Impacts Analysis..... L-9
34
35 L-4 Elements of the Regional Electricity Price Impacts Analysis..... L-14
36
37 L-5 Elements of the Regional Electricity Generating Capacity Expansion Impacts
38 Analysis..... L-16
39
40

TABLES

1
2
3
4 1-1 Glen Canyon Dam Release Constraints under Modified Low Fluctuating Flows 1-21
5
6 1-2 Selected Documents Included in the Law of the River 1-32
7
8 2-1 Operational Characteristics of LTEMP Alternatives 2-9
9
10 2-2 Condition-Dependent and Experimental Elements of LTEMP Alternatives 2-11
11
12 2-3 Flow Parameters under Alternative A in an 8.23-maf Year 2-16
13
14 2-4 Flow Parameters under Alternative B in an 8.23-maf Year 2-20
15
16 2-5 Flow Parameters under Alternative C in an 8.23-maf Year 2-25
17
18 2-6 Implementation Criteria for Experimental Treatments of Alternative C 2-30
19
20 2-7 Flow Parameters for a Year with Low Summer Flows under Alternative C
21 in an 8.23-maf Year 2-41
22
23 2-8 Flow Parameters under Alternative D in an 8.23-maf Year 2-44
24
25 2-9 Implementation Criteria for Experimental Treatments of Alternative D 2-48
26
27 2-10 Flow Parameters for a Year with Low Summer Flows under Alternative D
28 in an 8.23-maf Year 2-65
29
30 2-11 Flow Parameters under Alternative E in an 8.23-maf Year 2-70
31
32 2-12 Flow Parameters under Alternative F in an 8.23-maf Year 2-79
33
34 2-13 Flow Parameters under Alternative G in an 8.23-maf Year 2-80
35
36 2-14 Summary of Impacts of LTEMP Alternatives on Resources 2-89
37
38 3.5-1 Native Fish of the Colorado River through Glen and Grand Canyons 3-68
39
40 3.5-2 Nonnative Fish Found in Colorado River through Glen and Grand Canyons 3-86
41
42 3.5-3 Mean Water Temperature and Turbidity for Selected Sites in the Colorado
43 River Mainstem from 2006 to 2009 3-89
44
45 3.5-4 Nonnative Warmwater Fish Species Reported from the Little Colorado River
46 Watershed 3-96

TABLES (Cont.)

1
2
3
4 3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and
5 Channel Margins3-107
6
7 3.6-2 Special Status Plant Species Known to Occur along the Colorado River from
8 Glen Canyon Dam to Lake Mead3-116
9
10 3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife
11 Species along the Colorado River Corridor between Glen Canyon Dam and
12 Lake Mead3-127
13
14 3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–20133-169
15
16 3.10-2 Tolerable Daily Flow Fluctuations Reported by Commercial and Private
17 Trip Leaders3-176
18
19 3.13-1 Energy and Capacity Characteristics of the Eight Largest Western
20 Customers, 20133-199
21
22 3.14-1 Population in the Six-County Region3-202
23
24 3.14-2 Income in the Six-County Region3-203
25
26 3.14-3 Employment in the Six-County Region3-204
27
28 3.14-4 Employment by Sector in 20113-205
29
30 3.14-5 Unemployment Rates in the Six-County Region3-206
31
32 3.14-6 Minority and Low-Income Populations in the 11-County Area3-209
33
34 3.14-7 Population in the Seven-State Region of Influence3-213
35
36 3.14-8 Income in the Seven-State Region of Influence3-214
37
38 3.14-9 Employment in the Seven-State Region of Influence3-215
39
40 3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence3-216
41
42 3.14-11 Unemployment in the Seven-State Region of Influence3-217
43
44 3.14-12 State Minority and Low-Income Populations, 20103-218
45
46 3.15-1 Clean Air Act Prevention of Significant Deterioration Designations3-221

TABLES (Cont.)

1
2
3
4 3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand
5 Canyon National Park and for the Navajo Generating Station, 2011.....3-221
6
7 3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010,
8 over the 11-State Affected Area within the Western Interconnect.....3-226
9
10 4.1-1 Experimental Elements Included in Long-Term Strategies Associated with
11 Each LTEMP Alternative 4-4
12
13 4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water
14 Quality 4-13
15
16 4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees
17 Ferry to Diamond Creek..... 4-47
18
19 4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources 4-69
20
21 4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative 4-86
22
23 4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated
24 with Flow, Water Temperature, Water Quality, and Sediment Resources 4-88
25
26 4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology.....4-103
27
28 4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic
29 Food Base4-110
30
31 4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels4-153
32
33 4.6-2 Vegetation States and Corresponding Mapped Vegetation Types4-156
34
35 4.6-3 Summary of Impacts on Old High-Water Zone, New High-Water Zone, and
36 Wetland Plant Community Types4-158
37
38 4.6-4 Transitions between Riparian Community Types and the Flows That Initiate
39 Transitions4-166
40
41 4.6-5 Priority Nonnative Species Identified for Control within the Colorado River
42 Corridor4-171
43
44 4.6-6 Summary of Impacts on Special Status Plant Species under LTEMP
45 Alternatives.....4-174
46

TABLES (Cont.)

1
2
3
4 4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife4-189
5
6 4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife
7 Species4-199
8
9 4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen
10 and Grand Canyons4-221
11
12 4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover.....4-233
13
14 4.9-2 Summary of Impacts on Tribal Resources4-243
15
16 4.10-1 Summary of Impacts of LTEMP Alternatives on Visitor Use and Experience4-259
17
18 4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience.....4-283
19
20 4.13-1 Summary of the Impacts of LTEMP Alternatives on Hydropower Resources4-307
21
22 4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and
23 Environmental Justice4-328
24
25 4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP
26 Alternatives.....4-336
27
28 4.14-3 Recreational Visitation by Activity in Lake Powell, Upper and Lower Grand
29 Canyon, and Lake Mead, 2012.....4-339
30
31 4.14-4 Mean Annual Employment Associated with Recreational Expenditures
32 under LTEMP Alternatives4-339
33
34 4.14-5 Mean Annual Income Associated with Recreational Expenditures
35 under LTEMP Alternatives4-340
36
37 4.14-6 Seven-State Economic Impacts under LTEMP Alternatives of Additional
38 Generating Capacity for the Eight Largest Customer Utilities, 2015–20334-341
39
40 4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential
41 Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to
42 Alternative A4-342
43
44 4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers4-347
45
46

TABLES (Cont.)

1
2
3
4 4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air
5 Quality4-361
6
7 4.15-2 Distributions of SO₂ and NO_x Emissions Averaged over the 20-Year LTEMP
8 Period by Alternative.....4-364
9
10 4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions4-373
11
12 4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under
13 Climate Change Compared to Those under Historic Conditions4-378
14
15 4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable
16 Future Actions and Basin-Wide Trends in the LTEMP Project Area4-383
17
18 4.17-2 Summary of Cumulative Impacts and Incremental Contributions from LTEMP
19 Alternatives.....4-399
20
21 5.1-1 Summary of Cooperating Agency Involvement..... 5-3
22
23 B-1 Tolerable Flow Fluctuations for Recreational River Use..... B-13
24
25 D-1 Initial Reservoir Conditions D-5
26
27 D-2 Monthly Release Volumes by Water Year Release for Alternative A D-11
28
29 D-3 Monthly Release Volumes by Water Year Release for Alternative B D-12
30
31 D-4 Monthly Release Volumes by Water Year Release for Alternative C D-13
32
33 D-5 Monthly Release Volumes by Water Year Release for Alternative C with Low
34 Summer Flows..... D-14
35
36 D-6 Monthly Release Volumes by Water Year Release for Alternative D D-15
37
38 D-7 Monthly Release Volumes by Water Year Release for Alternative D with Low
39 Summer Flows..... D-16
40
41 D-8 Monthly Release Volumes by Water Year Release for Alternative E D-17
42
43 D-9 Monthly Release Volumes by Water Year Release for Alternative E with Low
44 Summer Flows..... D-18
45
46 D-10 Monthly Release Volumes by Water Year Release for Alternative F..... D-19

TABLES (Cont.)

1
2
3
4 D-11 Monthly Release Volumes by Water Year Release for Alternative G..... D-20
5
6 D-12 Minimum Release Constraints Used for Each Alternative..... D-21
7
8 D-13 Input Demands, by State..... D-27
9
10 E-1 Sources for Historical Tributary Sediment Load Data E-38
11
12 E-2 Historical Periods Used for Paria Sediment Traces s1, s2, and s3 E-38
13
14 E-3 Historical Periods Used for Little Colorado River Sediment Traces s1,
15 s2, and s3 E-38
16
17 E-4 List of HFEs Available for Sediment-Triggered Events E-39
18
19 F-1 Average Mean Habitat-Weighted Invertebrate Biomass at Select Sites in the
20 Colorado River, July 2006–June 2009 F-8
21
22 F-2 Average Mean Habitat-Weighted Invertebrate Production at Select Sites in the
23 Colorado River, July 2006–June 2009 F-9
24
25 F-3 Average Mean Habitat-Weighted Invertebrate Abundance at Select Sites in the
26 Colorado River, July 2006–June 2009 F-10
27
28 F-4 Distribution, Ecological Importance, and Favorable Temperature Range for
29 Select Primary Producers F-11
30
31 F-5 Temperature Requirements for Common Zooplankton F-24
32
33 F-6 Distribution, Importance to Higher Trophic Levels, and Temperature Range for
34 Common Benthic Macroinvertebrates Downstream of Glen Canyon Dam..... F-25
35
36 F-7 Temperature Requirements for the Asian Tapeworm, Anchor Worm, and Trout
37 Nematode..... F-26
38
39 F-8 Summary of Metrics Values from the Rainbow Trout-Humpback Chub Model..... F-53
40
41 F-9 Description of Input Parameters for the LTEMP Temperature Suitability Model..... F-66
42
43 F-10 Humpback Chub Aggregation Locations F-67
44
45 F-11 Locations Used for Temperature Suitability Modeling of Native Fish,
46 Nonnative Fish, and Parasites..... F-73

TABLES (Cont.)

1
2
3
4 G-1 Vegetation States, Plant Associations, and Corresponding Submodels G-15
5
6 G-2 Hydrologic Events Considered in the Riparian Vegetation Model G-16
7
8 G-3 Riparian Vegetation Model Transition Rules G-17
9
10 G-4 New High-Water Zone and Old High-Water Zone Vegetation Classes Mapped
11 from Lees Ferry to Diamond Creek G-22
12
13 G-5 Vegetation States and Corresponding Mapped Vegetation Types G-24
14
15 G-6 Example Results for the Native Cover Metric G-25
16
17 G-7 Example Results for the Arrowweed Metric G-25
18
19 G-8 Results for Alternative A G-26
20
21 G-9 Results for Alternative B, Long-Term Strategy B1 G-27
22
23 G-10 Results for Alternative B, Long-Term Strategy B2 G-28
24
25 G-11 Results for Alternative C, Long-Term Strategy C1 G-29
26
27 G-12 Results for Alternative C, Long-Term Strategy C2 G-30
28
29 G-13 Results for Alternative C, Long-Term Strategy C3 G-31
30
31 G-14 Results for Alternative C, Long-Term Strategy C4 G-32
32
33 G-15 Results for Alternative D, Long-Term Strategy D1 G-33
34
35 G-16 Results for Alternative D, Long-Term Strategy D2 G-34
36
37 G-17 Results for Alternative D, Long-Term Strategy D3 G-35
38
39 G-18 Results for Alternative D, Long-Term Strategy D4 G-36
40
41 G-19 Results for Alternative E, Long-Term Strategy E1 G-37
42
43 G-20 Results for Alternative E, Long-Term Strategy E2 G-38
44
45 G-21 Results for Alternative E, Long-Term Strategy E3 G-39
46

TABLES (Cont.)

1
2
3
4 G-22 Results for Alternative E, Long-Term Strategy E4..... G-40
5
6 G-23 Results for Alternative E, Long-Term Strategy E5..... G-41
7
8 G-24 Results for Alternative E, Long-Term Strategy E6..... G-42
9
10 G-25 Results for Alternative F..... G-43
11
12 G-26 Results for Alternative G..... G-44
13
14 I-1 Federal Regulations and Executive Orders Pertaining to Consultation with
15 Tribes..... I-3
16
17 I-2 Vegetation States..... I-5
18
19 J-1 Reported Mean Tolerable Daily Changes in Flow Levels for Commercial
20 Motor Guides, Commercial Oar Guides, and Private Trip Leaders..... J-12
21
22 J-2 Recreation Response to Daily Maximum Flow..... J-20
23
24 J-3 Summary of Recreation, Visitor Use, and Experience Metrics..... J-25
25
26 K.1-1 Cost and Performance Characteristics of Capacity Expansion Candidates..... K-51
27
28 K.1-2 Cumulative Annual Percent Increase in Natural Gas Prices at the Henry Hub..... K-54
29
30 K.1-3 Cumulative Annual Percent Increase in Regional Coal Prices..... K-57
31
32 K.1-4 Cumulative Annual Percent Increase in Regional Distillate Fuel Prices..... K-59
33
34 K.1-5 Assumed Ancillary Services Provided by SLCA/IP Hydropower Facilities from
35 2013 to 2030..... K-64
36
37 K.1-6 Summary of Utility IRPS for Four Large SLCA/IP Customers and Other Large
38 Utilities in Areas Neighboring the SLCA/IP System..... K-86
39
40 K.1-7 SLCA/IP Marketable Capacity at the 90% Exceedance Level..... K-101
41
42 K.1-8 Difference in Cumulative Capacity Additions of Each Alternative Relative to
43 Alternative A..... K-104
44
45 K.1-9 Comparison of the Amount and Timing of New Capacity Additions for
46 Alternatives A and F..... K-106

TABLES (Cont.)

1
2
3
4 K.1-10 Total Economic Impacts by Alternative at the 90% Exceedance LevelK-108
5
6 K.1-11 Estimated Cost of LTEMP ExperimentsK-115
7
8 K.1-12 Comparison of Marketable Capacity, Replacement Capacity, and Capacity
9 Additions by Exceedance LevelK-116
10
11 K.1-13 Firm SLCA/IP Federal Hydropower Capacity at Various Exceedance Levels at
12 Glen Canyon Dam by Alternative and Ancillary Service Scenarios.....K-125
13
14 K.1-14 Comparison of Capacity and Energy Values at Glen Canyon Dam by
15 Alternative and Ancillary Services Scenarios at the 90% Exceedance Level.....K-126
16
17 K.1-15 Difference Relative to Alternative A.....K-127
18
19 K.1-16 Summary of Economic Rankings for Baseline and All Sensitivity ScenariosK-128
20
21 K.2-1 SHP Contractual Obligations and Project Use Required Deliveries by MonthK-132
22
23 K.2-2 SHP Hourly Load Shapes by Month and Type of DayK-133
24
25 K.2-3 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion
26 by Alternative and Year.....K-137
27
28 K.2-4 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion
29 by Alternative and Year Expressed as the Difference from Alternative AK-139
30
31 K.2-5 Total Net Purchase Power Expenses by Year and Alternative for the
32 Continuous Current Obligations ScenarioK-143
33
34 K.2-6 Total Net Purchase Power Expenses by Year and Alternative for the Reduced
35 Obligations to Match Resource ScenarioK-144
36
37 K.2-7 SLCA/IP Rate Impact by Alternative.....K-147
38
39 K.3-1 Energy Allocations for Systems Receiving Indirect SLCA/IP AllocationsK-153
40
41 K.3-2 Coverage of Retail Information from EIA Database Relative to SLCA/IP
42 Preference Power Allocation.....K-154
43
44 K.3-3 Average Annual Grid Cost Relative to SLCA/IP Wholesale Revenues Relative
45 to Alternative AK-164
46

TABLES (Cont.)

1
2
3
4 K.3-4 Summary Table of Comparative ValuesK-174
5
6 K.3-5 Individual Systems with the Largest Percent Retail Rate Impacts Relative to
7 Alternative AK-175
8
9 K.3-6 Individual Systems with the Smallest Percent Retail Rate Impacts Relative to
10 Alternative AK-177
11
12 K.3-7 Individual Systems with the Largest Monthly Residential Bill Impacts Relative
13 to Alternative AK-179
14
15 K.3-8 Individual Systems with the Smallest Monthly Residential Bill Impacts
16 Relative to Alternative A.....K-180
17
18 K.3-9 Size and Preference Ratio for Utility Systems with Large Rate Impacts.....K-181
19
20 K.3-10 Rate Impacts for Selected Groups in Maximum Impact YearK-182
21
22 K.4-1 Monthly Change in Residential Electric Utility Bill for Tribes by AlternativeK-192
23
24 K.4-2 Total Dollar Annual Impact on Tribes under LTEMP Alternatives Relative to
25 Alternative AK-194
26
27 L-1 Total Regional Economic Impacts of Non-Local Recreation Expenditures, 2013 L-12
28
29 L-2 Urban Population, Income, and Poverty in the Six-County Region..... L-17
30
31 M-1 Emission Factors by Plant for System Power Generation and Spot MarketM-10
32
33 M-2 Power Generation Averaged over the 20-Year LTEMP Period by AlternativeM-12
34
35 M-3 Summary of Potential Impacts of LTEMP Alternatives on Visibility and
36 Regional Air QualityM-15
37
38 M-4 Annual SO₂ Emissions Averaged over the 20-Year LTEMP Period by
39 AlternativeM-16
40
41 M-5 Annual NO_x Emissions Averaged over the 20-Year LTEMP Period by
42 AlternativeM-19
43
44 M-6 Distributions of SO₂ and NO_x Emissions Averaged over the 20-Year LTEMP
45 Period by Alternative.....M-22
46

TABLES (Cont.)

1
2
3
4 M-7 Annual Greenhouse Gas Emissions Averaged over the 20-Year LTEMP Period
5 by AlternativeM-23
6
7 M-8 Summary of Potential Impacts of LTEMP Alternatives on CO₂e EmissionsM-26
8
9 N-1 Summary of Tribal Participation Status N-5
10
11 N-2 Summary of Tribal Correspondence N-6
12
13 N-3 Summary of Major Face-to-Face Meetings, Webinars, and Conference Calls
14 Involving Tribes N-25
15
16 N-4 Summary of Individual Tribal Consultation Meetings to Date N-26
17
18 N-5 Index of Project Tribal Government Consultation and Coordination
19 Correspondence N-28
20

1
2
3
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5
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ACRONYMS AND ABBREVIATIONS

1		
2		
3		
4	ac	acre(s)
5	ac-ft	acre-foot (feet)
6	ACHP	Advisory Council on Historic Preservation
7	AML	abandoned mine land
8	AMSL	above mean sea level
9	AMWG	Adaptive Management Work Group
10	AOP	Annual Operation Plan for Colorado River Reservoirs
11	APE	Area of Potential Effect
12	Argonne	Argonne National Laboratory
13	ASMR	Age-Structured Mark Recapture Model
14	AZGFD	Arizona Game and Fish Department
15	AZ-SGCN	Arizona Species of Greatest Conservation Need
16		
17	BA	Balancing Authority (in Chapter 3 only)
18		Biological Assessment (in all other sections)
19	BGEPA	Bald and Golden Eagle Protection Act of 1940
20	BIA	Bureau of Indian Affairs
21	BO	Biological Opinion
22		
23	C	Celsius
24	CAA	Clean Air Act
25	CAAA	Clean Air Act Amendments
26	CAEDYM	Computational Aquatic Ecosystem Dynamics Model
27	CCC	Civilian Conservation Corps
28	CEQ	Council on Environmental Quality
29	CFMP	<i>Comprehensive Fisheries Management Plan</i>
30	CFR	<i>Code of Federal Regulations</i>
31	cfs	cubic feet per second
32	CH ₄	methane
33	CO	carbon monoxide
34	CO ₂	carbon dioxide
35	CO ₂ e	carbon dioxide equivalent
36	CPUE	catch per unit effort
37	CRBC	Colorado River Board of California
38	CRCN	Colorado River Commission of Nevada
39	CRD	Colorado River Discovery
40	CREDA	Colorado River Energy Distributors Association
41	CRMP	Colorado River Management Plan
42	CRSP	Colorado River Storage Project
43	CRSPA	Colorado River Storage Project Act of 1956
44	CRSS	Colorado River Simulation System
45	CSU	Colorado Springs Utilities
46		

1	DEIS	Draft Environmental Impact Statement
2	Deseret	Deseret Generation and Transmission Cooperative
3	DFC	desired future condition
4	DO	dissolved oxygen
5	DOE	U.S. Department of Energy
6	DOI	U.S. Department of the Interior
7	DPS	Distinct Population Segment
8		
9	EA	Environmental Assessment
10	eGRID	Emissions & Generation Resource Integrated Database
11	EIA	Energy Information Administration
12	EIR	Environmental Impact Report
13	EIS	Environmental Impact Statement
14	ELCOM	Estuary, Lake and Coastal Ocean Model
15	EMS	emergency medical services
16	E.O.	Executive Order
17	EPA	U.S. Environmental Protection Agency
18	EPT	Ephemeroptera, Plecoptera, and Trichoptera
19	ESA	Endangered Species Act of 1973, as amended
20		
21	F	Fahrenheit
22	FCPP	Four Corners Power Plant
23	FES	Firm Electric Service
24	FONSI	Finding of No Significant Impact
25	FR	<i>Federal Register</i>
26	ft	foot (feet)
27	FWS	U.S. Fish and Wildlife Service
28	FY	fiscal year
29		
30	GCDAMP	Glen Canyon Dam Adaptive Management Program
31	GCM	general circulation model
32	GCMRC	Grand Canyon Monitoring and Research Center
33	GCNP	Grand Canyon National Park
34	GCNRA	Glen Canyon National Recreation Area
35	GCPA	Grand Canyon Protection Act of 1992
36	GHG	greenhouse gas
37	GMP	General Management Plan
38	GW	gigawatt(s)
39	GWh	gigawatt-hour(s)
40	GWP	global warming potential
41		
42	H ₂ S	hydrogen sulfide
43	HBC	humpback chub
44	HFC	hydrofluorocarbon
45	HFE	high-flow experiment
46	hr	hour(s)

1	HRR	Hualapai River Runners
2		
3	in.	inch(es)
4	IPM	Integrated Pest Management
5	IRP	integrated resource plan
6	ISM	Indexed Sequential Method
7		
8	kaf	thousand acre-feet
9	kWh	kilowatt-hour(s)
10		
11	lb	pound(s)
12	LCRMSCP	Lower Colorado River Multi-Species Conservation Program
13	LMM	Lake Mead Model
14	LMNRA	Lake Mead National Recreation Area
15	LROC	Long-Range Operating Criteria
16	LTEMP	Long-Term Experimental and Management Plan
17	LTEP	Long Term Experimental Plan
18	LTF	long-term firm
19		
20	maf	million acre-feet
21	MAMB	miscellaneous algae, macrophytes, and bryophytes
22	MBTA	Migratory Bird Treaty Act
23	MCL	maximum contaminant level
24	mi	mile(s)
25	MLFF	Modified Low Fluctuating Flow
26	MMt	million metric tons
27	MOA	Memorandum of Agreement
28	MT	metric ton(s)
29	MW	megawatt(s)
30	MWh	megawatt-hour(s)
31		
32	N ₂ O	nitrous oxide
33	NAAQS	National Ambient Air Quality Standards
34	NAU	Northern Arizona University
35	NC	no change
36	NEPA	National Environmental Policy Act of 1969, as amended
37	NERC	North American Electric Reliability Corporation
38	NEV	net economic use value
39	NGO	nongovernmental organization
40	NHPA	National Historic Preservation Act
41	NM	national monument
42	NO ₂	nitrogen dioxide
43	NO ₃	nitrate-nitrogen
44	NOI	Notice of Intent
45	NO _x	nitrogen oxides
46	NPS	National Park Service

1	NPV	net present value
2	NRHP	<i>National Register of Historic Places</i>
3	NTUA	Navajo Tribal Unit Authority
4		
5	O&M	operation and maintenance
6	O ₃	ozone
7	OPAC	Office of Planning and Compliance
8	OSMRE	Office of Surface Mining Reclamation and Enforcement
9		
10	PA	Programmatic Agreement
11	Pb	lead
12	PEPC	Planning, Environment, and Public Comment
13	PFC	perfluorocarbon
14	P.L.	Public Law
15	PM	particulate matter
16	PM _{2.5}	particulate matter ≤2.5 μm in aerodynamic diameter
17	PM ₁₀	particulate matter ≤10 μm in aerodynamic diameter
18	POM	particulate organic matter
19	PSAR	preventative search and rescue
20	PSD	Prevention of Significant Deterioration
21		
22	RA	resource available
23	Reclamation	Bureau of Reclamation
24	RM	river mile
25	RMP	Resource Management Plan
26	ROD	Record of Decision
27	RSG	Reserve Sharing Group
28		
29	SAAQS	State Ambient Air Quality Standards
30	SBM	Sand Budget Model
31	SCP	Salinity Control Project
32	SD	standard deviation
33	SDA	Structured Design Analysis
34	SE	standard error
35	Secretary, the	Secretary of the Interior
36	SF ₆	sulfur hexafluoride
37	SHPO	State Historic Preservation Officer
38	SLCA/IP	Salt Lake City Area Integrated Projects
39	SO	Secretarial Order
40	SO ₂	sulfur dioxide
41	SPC	Southern Paiute Consortium
42	SRP	Salt River Project
43	SRSG	Southwest Reserve Sharing Group
44		
45	TCD	temperature control device
46	TCP	traditional cultural property

1	TDS	total dissolved solids
2	THPO	Tribal Historic Preservation Officer
3	TL	total length
4	TMF	trout management flow
5	Tri-State	Tri-State Generation and Transmission Association
6	TWG	Technical Working Group
7		
8	UAMPS	Utah Associated Municipal Power Systems
9	UBWR	Utah Board of Water Resources
10	UCRC	Upper Colorado River Commission
11	UMPA	Utah Municipal Power Agency
12	USC	<i>United States Code</i>
13	USFS	U.S. Forest Service
14	USGS	U.S. Geological Survey
15		
16	VOC	volatile organic compound
17		
18	WACM	Western Area Colorado-Missouri Region
19	WALC	Western Area Lower Colorado Region
20	WAUW	Western Area Upper Great Plains West Region
21	WECC	Western Electricity Coordinating Council
22	Western	Western Area Power Administration
23		
24	YOY	young-of-year
25	yr	year(s)
26		
27	ZHHPO	Zuni Heritage and Historic Preservation Office
28		

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1 INTRODUCTION

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3
4 The U.S. Department of the Interior (DOI), through the Bureau of Reclamation
5 (Reclamation) and National Park Service (NPS) proposes to develop and implement a Long-
6 Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam, the
7 largest unit of the Colorado River Storage Project (CRSP). The LTEMP would provide a
8 framework for adaptively managing Glen Canyon Dam operations over the next 20 years
9 consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of
10 applicable federal law. The LTEMP would determine specific options for dam operations,
11 non-flow actions, and appropriate experimental and management actions that will meet the
12 GCPA's requirements and minimize impacts on resources within the area impacted by dam
13 operations, commonly referred to as the Colorado River Ecosystem, including those of
14 importance to American Indian Tribes.

15
16 This LTEMP Draft Environmental Impact Statement (DEIS) has been prepared to
17 identify the potential environmental effects of implementing the proposed federal action. In
18 addition, this DEIS identifies and analyzes the environmental issues and consequences associated
19 with taking no action, as well as a reasonable range of alternatives to no action for implementing
20 the proposed federal action. The alternatives addressed in this DEIS include a broad range of
21 operations and experimental actions that together allow for a full evaluation of possible impacts
22 of the proposed action. DOI, through Reclamation and NPS, has determined these alternatives
23 represent a reasonable range of options that would meet the purpose, need, and objectives (as
24 described below) of the proposed action. This DEIS has been developed in accordance with the
25 National Environmental Policy Act of 1969, as amended (NEPA), following implementing
26 regulations developed by the President's Council on Environmental Quality (CEQ) in Title
27 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations implementing
28 NEPA in 43 CFR Part 46.

29
30 Reclamation and NPS are joint-lead agencies for the LTEMP DEIS because of their
31 complementary roles in operating Glen Canyon Dam (Reclamation's role) and managing the
32 resources of Glen Canyon National Recreation Area (GCNRA) and Grand Canyon National Park
33 (GCNP) (NPS's role). As joint leads, both agencies have been equally involved in the
34 development of all aspects of the LTEMP DEIS. Major phases of LTEMP DEIS development
35 included (1) public and internal scoping, (2) identification of alternatives to be considered for
36 evaluation and their characteristics, (3) identification of elements common to all alternatives,
37 (4) analysis of the consequences of the alternatives, (5) government-to-government consultation
38 with traditionally associated Tribes, and (6) preparation of the DEIS.

39
40 The first Environmental Impact Statement (EIS) on the operation of Glen Canyon Dam
41 was published in 1995 (Reclamation 1995). The 1996 Record of Decision (ROD)
42 (Reclamation 1996) selected the Modified Low Fluctuating Flow Alternative as the preferred
43 means of operating Glen Canyon Dam. The ROD incorporated the GCPA requirement that the
44 Secretary of the Interior (hereafter referred to as the Secretary) undertake research and
45 monitoring to determine if revised dam operations were achieving the resource protection
46 objectives of the final EIS and the ROD. The ROD also led to the establishment of the Glen

1 Canyon Dam Adaptive Management Program (GCDAMP), administered by Reclamation with
2 technical expertise provided by the U.S. Geological Survey's (USGS's) Grand Canyon
3 Monitoring and Research Center (GCMRC).
4

5 The following passage was included in the 1995 EIS for the purposes of providing
6 background and context to the public. This section provides relevant content and context for this
7 LTEMP DEIS and is therefore reproduced here for public information:
8

9 The underlying project purpose(s) is defined by section 1 of the Colorado River
10 Storage Project Act of 1956 (43 United States Code (U.S.C.) 620), which
11 authorized the Secretary to "construct, operate, and maintain" Glen Canyon Dam:
12

13 ...for the purposes, among others, of regulating the flow of the Colorado River,
14 storing water for beneficial consumptive use, making it possible for the States of
15 the Upper Basin to utilize, consistently with the provisions of the Colorado River
16 Compact, the apportionments made to and among them in the Colorado River
17 Compact and the Upper Colorado River Basin Compact, respectively, providing
18 for the reclamation of arid and semiarid land, for the control of floods, and for the
19 generation of hydroelectric power, as an incident of the foregoing purposes...
20

21 In 1968, Congress enacted the Colorado River Basin Project Act (43 U.S.C. 1501
22 et seq.). This act provided for a program for further comprehensive development
23 of Colorado River Basin water resources. Section 1501(a) states:
24

25 This program is declared to be for the purposes, among others, of regulating the
26 flow of the Colorado River; controlling flood; improving navigation; providing
27 for the storage and delivery of waters of the Colorado River for reclamation of
28 lands, including supplemental water supplies, and for municipal, industrial, and
29 other beneficial purposes; improving water quality; providing for basic public
30 outdoor recreation facilities; improving conditions for fish and wildlife, and the
31 generation and sale of electrical power as an incident of the foregoing purposes.
32

33 In addition, the Criteria for Coordinated Long Range Operation of Colorado River
34 Reservoirs (including Glen Canyon Dam) were mandated by section 1552 of the
35 Colorado River Basin Project Act. Article 1.(2) of these criteria requires that the
36 Annual Operating Plan for Colorado River reservoirs:
37

38 ...shall reflect appropriate consideration of the uses of the reservoirs for all
39 purposes, including flood control, river regulation, beneficial consumptive uses,
40 power production, water quality control, recreation, enhancement of fish and
41 wildlife, and other environmental factors.
42

43 The Colorado River Compact (1922) and the Upper Colorado River Basin
44 Compact (1948) do not affect obligations to Native American interests.
45 Article VII and Article XIX, part a respectively, of the 1922 and 1948 compacts
46 provide that:

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

3
4 The Colorado River Storage Project Act of 1956, the Colorado River Basin
5 Project Act of 1968, and the associated Criteria for Coordinated Long-Range
6 Operation of Colorado River Reservoirs (Long-Range Operating Criteria) did not
7 alter these compact provisions.

8
9 In addition to the Secretary's decision calling for a reevaluation, Congress
10 subsequently enacted the Grand Canyon Protection Act of 1992. Section 1802 (a)
11 of the act requires the Secretary to operate Glen Canyon Dam:

12
13 ... in accordance with the additional criteria and operating plans specified in
14 section 1804 and exercise other authorities under existing law in such a manner as
15 to protect, mitigate adverse impacts to, and improve the values for which Grand
16 Canyon National Park and Glen Canyon National Recreational Area were
17 established, including, but not limited to natural and cultural resources and visitor
18 use.

19
20 Section 1802(b) of the act further requires that the above mandate be implemented
21 in a manner fully consistent with existing law¹. Section 1802(c) states that the
22 purposes for which Grand Canyon National Park and Glen Canyon National
23 Recreation Area were established are unchanged by the act. Section 1804 (a) of
24 the act requires the Secretary to complete an EIS no later than October 30, 1994,
25 following which, under section 1804 (c), the Secretary is to 'exercise other
26 authorities under existing law, so as to ensure that Glen Canyon Dam is operated
27 in a manner consistent with section 1802.' Section 1804 (c) also requires that the
28 criteria and operating plans are to be 'separate from and in addition to those
29 specified in section 602 (b) of the Colorado River Basin Project Act of 1968.'

30
31 Glen Canyon Dam was completed by the Bureau of Reclamation (Reclamation) in
32 1963, prior to enactment of the National Environmental Policy Act of 1969
33 (NEPA). Consequently, no EIS was filed regarding the construction or operation
34 of Glen Canyon Dam. Since the dam has long been completed, alternatives to the
35 dam itself have been excluded from the scope of the analysis.

36
37 The DOI has evaluated information developed through the GCDAMP to more fully
38 inform decisions regarding operation of Glen Canyon Dam over the next 20 years and to inform
39 other management and experimental actions within the LTEMP. Revised dam operations and
40 other actions will be considered and analyzed under alternatives in this DEIS.

41

¹ The Secretary shall implement this section in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of the Colorado River Storage Project Act of 1956 (CRSPA) and the Colorado River Basin Project Act of 1968, that govern allocation, appropriation, development, and exportation of the waters of the Colorado River basin.

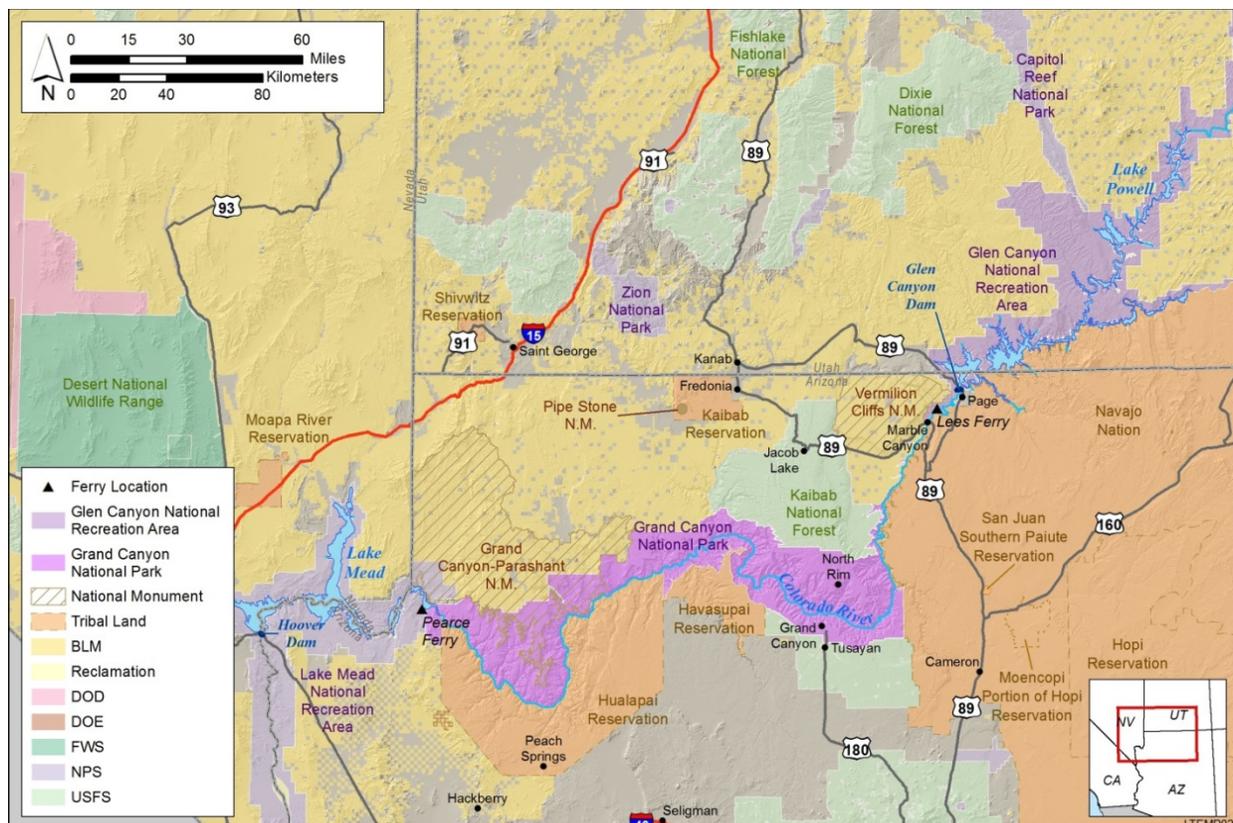
1 The LTEMP will incorporate information gathered since the 1996 ROD, including status
2 reports developed in coordination with the GCDAMP and Reclamation and NPS compliance
3 documents supporting adaptive management efforts for the Glen Canyon Dam. These include,
4 but are not limited to, the *Environmental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

10
11 A previous planning process, called the Long Term Experimental Plan (LTEP) for the
12 operation of Glen Canyon Dam, commenced in late 2006. In February 2008, the LTEP EIS was
13 put on hold until the completion of environmental compliance on a 5-year plan of experimental
14 flows (2008–2012), including a high-flow test completed in March 2008 and yearly fall steady
15 flows conducted each year in September and October from 2008 to 2012. As stated in the Notice
16 of Intent (NOI) in the *Federal Register* on July 6, 2011 (DOI 2011b), the LTEMP DEIS
17 supersedes the LTEP EIS. This LTEMP DEIS draws on the environmental documentation and
18 updated information developed for the LTEP EIS.

19 20 21 **1.1 DESCRIPTION OF THE PROPOSED ACTION**

22
23 The proposed federal action considered in this DEIS, as described in the 2011 NOI and as
24 further refined in this DEIS, is the development and implementation of a structured, long-term
25 experimental and management plan for operations of Glen Canyon Dam. The LTEMP and the
26 Secretary’s decision would provide a framework for adaptively managing Glen Canyon Dam
27 operations and other management and experimental actions over the next 20 years consistent
28 with the GCPA and other provisions of applicable federal law. The LTEMP would determine
29 specific options for dam operations (including hourly, daily, and monthly release patterns),
30 non-flow actions, and appropriate experimental and management actions that will meet the
31 GCPA’s requirements, maintain or improve hydropower production, and minimize impacts on
32 resources, including those of importance to American Indian Tribes. The locations of Glen
33 Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and
34 adjacent lands are shown in Figure 1-1. Glen Canyon Dam is shown in Figure 1-2.

35
36 Under the LTEMP, water will continue to be delivered in a manner that is fully consistent
37 with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the
38 Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*,
39 and the provisions of the Colorado River Storage Project Act of 1956 (CRSPA) and the Colorado
40 River Basin Project Act of 1968 that govern allocation, appropriation, development, and
41 exportation of the waters of the Colorado River Basin, and consistent with applicable
42 determinations of annual water release volumes from Glen Canyon Dam made pursuant to the
43 Long-Range Operating Criteria for (LROC) Colorado River Basin Reservoirs, which are
44 currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and
45 Coordinated Operations for Lake Powell and Lake Mead. This LTEMP DEIS analyzes
46 alternative-specific ways to manage monthly, daily, and hourly releases from Glen Canyon Dam.



1

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

6

7

8 **1.2 PURPOSE OF AND NEED FOR ACTION**

9

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

13

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

19

20 The need for the proposed action stems from the need to use scientific information
 21 developed since the 1996 ROD to better inform DOI decisions on dam operations and other
 22 management and experimental actions so that the Secretary may continue to meet statutory
 23 responsibilities for protecting downstream resources for future generations, conserving species
 24 listed under the Endangered Species Act (ESA), avoiding or mitigating impacts on *National*



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FIGURE 1-2 Glen Canyon Dam

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

The purpose and need statement described above was modified from the July 6, 2011, *Federal Register* notice based on public and Cooperating Agency comments. The ESA Recovery Implementation Program was eliminated from further consideration, as described in Chapter 2; other refinements to the purpose and need statement were not substantively different from those described in the original notice.

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

- *Continued loss of sandbars.* The Colorado River downstream from Glen Canyon Dam is depleted of its natural sediment load due to the presence of the dam, and many types of ongoing dam releases further deplete sediment delivered to the main channel by causing erosion. However, high-flow releases, between approximately 30,000 and 45,000 cubic feet per second (cfs) that are triggered when there is sufficient sediment from the Paria River, mobilize sand stored in the river channel and redeposit it as sandbars and

1 beaches and associated backwater and riparian habitats (Melis et al. 2011).
2 This LTEMP DEIS uses current comprehensive scientific data and modeling
3 to consider possible improvements related to the use of high-flow experiments
4 (HFEs), as well as possible intervening flow operations that may help better
5 achieve the goal of retaining sand bars.
6

- 7 • *Humpback chub*. Since the 1995 EIS, the status of the humpback chub
8 (*Gila cypha*), listed as an endangered species, has continued to be an issue of
9 concern since the population in Grand Canyon, the largest in existence,
10 declined during the late 1990s, coincident with higher flow volumes, cooler
11 water temperatures, and high nonnative trout abundance, but has since
12 partially rebounded over the last decade when water temperatures were
13 warmer and trout abundance lower (Yackulic et al. 2014; Yard et al.
14 2011). Uncertainty in future humpback chub population response to
15 interactions among flows, nonnative trout, food base, and water temperatures
16 remains. This DEIS explicitly examines the scientific uncertainties related to
17 the relationships among trout, temperature, and the humpback chub
18 population and considers both flow (e.g., trout management flows) and
19 non-flow options (e.g., mechanical removal) and adaptive and experimental
20 actions to improve the status of humpback chub.
21
- 22 • *Rainbow trout fishery*. Rainbow trout (*Oncorhynchus mykiss*) are the basis of
23 the recreational fishery at Lees Ferry. Since 1964, the tailwaters of Glen
24 Canyon Dam have supported a recreational rainbow trout fishery that has
25 grown in importance and reputation locally, regionally, nationally, and
26 internationally. Anglers from around the world travel to Lees Ferry to fish for
27 high-quality rainbow trout. This blue-ribbon recreational sport fishery has
28 become a financial and economic mainstay for the community of Marble
29 Canyon, the City of Page, and Coconino County, as well as contributing to the
30 statewide economy. The existence of this fishery is due primarily to the
31 operations of Glen Canyon Dam and the aquatic productivity and food base
32 that its operations support. This DEIS evaluates the effects of flow and non-
33 flow actions of LTEMP alternatives on the Glen Canyon trout fishery.
34
- 35 • *Other native and nonnative fish*. In addition to humpback chub, the razorback
36 sucker (*Xyrauchen texanus*), also listed as endangered, and three other native
37 fish still occur in the Colorado River below Glen Canyon Dam. Razorback
38 sucker were thought to be extirpated from the Grand Canyon but have recently
39 been found in western Grand Canyon. Populations of bluehead and
40 flannelmouth suckers have fluctuated since the 1995 EIS. Numerous
41 nonnative fish species are also found in the Colorado River and tributaries,
42 and are numerically dominated by rainbow trout above the Little Colorado
43 River. Brown trout (*Salmo trutta*), channel catfish (*Ictalurus punctatus*),
44 common carp (*Cyprinus carpio*), and other species occur in many locations in
45 lower numbers. There is concern that the nonnative fish compete with or prey
46 upon the native or endangered fish to varying degrees. The effects of dam

1 operations were examined in the 1995 EIS, and much additional information
2 has been accumulated about the effects of dam operations on native and
3 nonnative fish. This DEIS applies the best available science and modeling
4 methods to further consider the impacts of a variety of dam operations and
5 non-flow actions on native and nonnative fish and determine what future
6 experimentation is needed regarding these flow regimes to reduce the negative
7 interactions of nonnative fish with native fish.
8

- 9 • *Cultural resources.* Cultural resources occur along the river corridor
10 downstream from Glen Canyon Dam in Glen, Marble, and Grand Canyons.
11 These resources are found both within the area directly affected by river flows
12 as well as on elevated terraces that have not been inundated by flows since
13 construction of the dam. Research conducted since the 1995 EIS on the
14 relationship between sand deposits and wind processes continues to provide
15 data that suggest that windblown sand changes the surface of some sites of
16 archaeological and cultural concern where sand supply and wind are active
17 agents (Draut and Rubin 2008; Draut 2012; Sankey and Draut 2014).
18 Additional research downstream from the dam is examining the relationship
19 between dam operations and ongoing erosion in areas of limited sand supply
20 (Collins et al. 2014). This LTEMP DEIS reexamines these relationships in
21 light of the most recent scientific studies.
22
- 23 • *Riparian vegetation.* Vegetation along the river corridor is affected by the
24 magnitude and seasonal pattern of river flows. Vegetation studies conducted
25 since 1995 indicate that riparian vegetation composition, structure,
26 distribution, and function are closely tied to ongoing dam operations. This
27 DEIS considers approaches to protecting, mitigating, and improving
28 vegetation in Glen and Grand Canyons.
29
- 30 • *Hydropower.* Power generated by Glen Canyon Dam serves 5.8 million retail
31 customers in Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and
32 Wyoming. Since 1995, new modeling tools have been created to better
33 analyze dam operations for hydropower and the impacts of altering operations
34 on electrical generation and capacity. This LTEMP DEIS applies peer-
35 reviewed science and modeling methods to further consider the impacts of a
36 variety of dam operations on power generation and capacity, and considers
37 operations that can minimize impacts on or improve hydropower and the
38 Basin Fund while striving to protect and improve other downstream resources.
39

40 Additional concerns related to dam operations were raised by the public at scoping
41 meetings and in comments submitted during the scoping of the DEIS. Such concerns included
42 restoration of the downstream Colorado River ecosystem; reestablishment of ecosystem patterns
43 and processes to their pre-dam range of natural variability; elimination or minimization of further
44 beach erosion; facilitation of sediment redeposition; in situ maintenance and preservation of the
45 integrity of cultural and archeological resources; elimination of adverse impacts on native
46 species and assistance in their recovery; nonnative fish management; assistance in repropagation

1 of the native riparian plant communities; and improving the hydropower resource. Public
2 scoping is discussed further in Section 1.5.

3 4 5 **1.3 LEAD AND COOPERATING AGENCIES AND CONSULTING TRIBES**

6
7 Federal agencies having management objectives include Reclamation, NPS, U.S. Fish
8 and Wildlife Service (FWS), Bureau of Indian Affairs (BIA), and Western Area Power
9 Administration (Western).

10 11 12 **1.3.1 Lead Agencies**

13
14 The DOI, through Reclamation and NPS, prepared this LTEMP DEIS with assistance
15 from Argonne National Laboratory (Argonne). Reclamation is primarily responsible for
16 operating Glen Canyon Dam. NPS is primarily responsible for conservation of the natural and
17 cultural resources and visitor experience in GCNP, GCNRA, and Lake Mead National
18 Recreation Area (LMNRA). Reclamation and NPS are joint-lead agencies in this process and
19 have cooperated on all aspects of the production of this LTEMP DEIS, including the overall
20 NEPA/EIS process, communication and consultation with Cooperating Agencies and other
21 stakeholders, and project schedule.

22 23 24 **1.3.2 Cooperating Agencies and Consulting Tribes**

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

29
30 In addition, 43 Tribes were formally invited to enter into government-to-government
31 consultation. In accordance with the requirements identified in Executive Order (E.O.) 13175,
32 “Consultation and Coordination with Indian Tribal Governments” (U.S. President 2000); the
33 President’s memorandum of April 29, 1994, “Government-to-Government Relations with Native
34 American Tribal Governments” (U.S. President 1994a); “Department of the Interior Policy on
35 Consultation with Indian Tribes;” the President’s memorandum of November 5, 2009, “Tribal
36 Consultation” (U.S. President 2009); agency-specific guidance on Tribal interactions; and
37 applicable natural and cultural resource laws and regulations (e.g., NEPA, ESA, National
38 Historic Preservation Act [NHPA], and Migratory Bird Treaty Act); Reclamation and NPS
39 coordinate and consult with federally recognized Tribes whose interests might be affected by
40 activities being considered in the LTEMP DEIS. Regular meetings have been held with Tribes
41 who indicated an interest in consultation in the LTEMP DEIS development process.

42
43 The Cooperating Agencies include three federal entities (BIA, FWS, and Western), three
44 state agencies (Arizona Game and Fish Department, Colorado River Board of California, and the
45 Colorado River Commission of Nevada), the Upper Colorado River Commission, two public
46 utilities (Salt River Project and Utah Associated Municipal Power Systems), and six Tribes

1 (the Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo
2 Nation, and the Pueblo of Zuni). Two additional Tribes—the Fort Mojave Indian Tribe and the
3 Gila River Indian Community—accepted the invitation to participate as consulting parties. Nine
4 others—the Pueblo of Santa Ana, the Fort Yuma Quechan, the Pueblo of Nambe, the Pueblo of
5 Santa Clara, the Pueblo of Zia, the Southern Ute Indian Tribe, the Ute Mountain Ute Indian
6 Tribe, the Paiute Indian Tribe of Utah, and Yavapai-Apache Nation—preferred to be on the
7 mailing list and kept informed regarding the LTEMP DEIS.
8
9

10 **1.4 OBJECTIVES AND RESOURCE GOALS OF THE LTEMP**

11

12 The DOI has identified several primary objectives of operating Glen Canyon Dam under
13 the LTEMP, as well as more specific goals to improve resources within the Colorado River
14 Ecosystem² through experimental and management actions. These objectives and resource goals
15 were considered in the formulation and development of alternatives in this DEIS.
16

17 The following is a list of the objectives of the LTEMP:
18

- 19 • Develop an operating plan for Glen Canyon Dam in accordance with the
20 GCPA to protect, mitigate adverse impacts on, and improve the values for
21 which GCNP and GCNRA were established, including, but not limited to,
22 natural and cultural resources and visitor use, and to do so in such a manner as
23 is fully consistent with and subject to the Colorado River Compact, the Upper
24 Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the
25 decree of the U.S. Supreme Court in *Arizona v. California*, and the provisions
26 of CRSPA and the Colorado River Basin Project Act of 1968 that govern the
27 allocation, appropriation, development, and exportation of the waters of the
28 Colorado River Basin (see Section 1.9.4) and in conformance with the Criteria
29 for Coordinated Long-Range Operations of Colorado River Reservoirs as
30 currently implemented by the 2007 Interim Guidelines for Lower Basin
31 Shortages and Coordinated Operations for Lake Powell and Lake Mead.
32
- 33 • Ensure water delivery to the communities and agriculture that depend on
34 Colorado River water consistent with applicable determinations of annual
35 water release volumes from Glen Canyon Dam made pursuant to the LROC
36 for Colorado River Basin Reservoirs, which are currently implemented
37 through the 2007 Interim Guidelines for Lower Basin Shortages and
38 Coordinated Operations for Lake Powell and Lake Mead.
39

² 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).

- 1 • Consider potential future modifications to Glen Canyon Dam operations and
2 other flow and non-flow actions to protect and improve downstream
3 resources.
- 4
- 5 • Maintain or increase Glen Canyon Dam electric energy generation, load
6 following capability, and ramp rate capability, and minimize emissions and
7 costs to the greatest extent practicable, consistent with improvement and long-
8 term sustainability of downstream resources.
- 9
- 10 • Respect the interests and perspectives of American Indian Tribes.
- 11
- 12 • Make use of the latest relevant scientific studies, especially those conducted
13 since 1996.
- 14
- 15 • Determine the appropriate experimental framework that allows for a range of
16 programs and actions, including ongoing and necessary research, monitoring,
17 studies, and management actions in keeping with the adaptive management
18 process.
- 19
- 20 • Identify the need for a Recovery Implementation Program for endangered fish
21 species below Glen Canyon Dam.
- 22
- 23 • Ensure Glen Canyon Dam operations are consistent with the GCPA, ESA,
24 NHPA, CRSPA, and other applicable federal laws.
- 25

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

- 29
- 30 1. *Archaeological and Cultural Resources*. Maintain the integrity of potentially
31 affected NRHP-eligible or listed historic properties in place, where possible,
32 with preservation methods employed on a site-specific basis.
- 33
- 34 2. *Natural Processes*. Restore, to the extent practicable, ecological patterns and
35 processes within their range of natural variability, including the natural
36 abundance, diversity, and genetic and ecological integrity of the plant and
37 animal species native to those ecosystems.
- 38
- 39 3. *Humpback Chub*. Meet humpback chub recovery goals, including maintaining
40 a self-sustaining population, spawning habitat, and aggregations in the
41 humpback chub's natural range in the Colorado River and its tributaries below
42 the Glen Canyon Dam.
- 43
- 44 4. *Hydropower and Energy*. Maintain or increase Glen Canyon Dam electric
45 energy generation, load following capability, and ramp rate capability, and

- 1 minimize emissions and costs to the greatest extent practicable, consistent
2 with improvement and long-term sustainability of downstream resources.
3
- 4 5. *Other Native Fish*. Maintain self-sustaining native fish species populations
5 and their habitats in their natural ranges on the Colorado River and its
6 tributaries.
7
- 8 6. *Recreational Experience*. Maintain and improve the quality of recreational
9 experiences for the users of the Colorado River ecosystem. Recreation
10 includes, but is not limited to, flatwater and whitewater boating, river corridor
11 camping, and angling in Glen Canyon.
12
- 13 7. *Sediment*. Increase and retain fine sediment volume, area, and distribution in
14 the Glen, Marble, and Grand Canyon reaches above the elevation of the
15 average base flow for ecological, cultural, and recreational purposes.
16
- 17 8. *Tribal Resources*. Maintain the diverse values and resources of traditionally
18 associated Tribes along the Colorado River corridor through Glen, Marble,
19 and Grand Canyons.
20
- 21 9. *Rainbow Trout Fishery*. Achieve a healthy high-quality recreational rainbow
22 trout fishery in GCNRA and reduce or eliminate downstream trout migration
23 consistent with NPS fish management and ESA compliance.
24
- 25 10. *Nonnative Invasive Species*. Minimize or reduce the presence and expansion
26 of aquatic nonnative invasive species.
27
- 28 11. *Riparian Vegetation*. Maintain native vegetation and wildlife habitat, in
29 various stages of maturity, such that they are diverse, healthy, productive,
30 self-sustaining, and ecologically appropriate.
31

32 In addition, the LTEMP was developed to ensure that water delivery continues in a
33 manner that is fully consistent with and subject to the Colorado River Compact, the Upper
34 Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the
35 Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River
36 Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of
37 the waters of the Colorado River Basin, and consistent with applicable determinations of annual
38 water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado River
39 Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for
40 Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.
41

42 43 **1.5 SCOPE OF THE DEIS** 44

45 On December 10, 2009, then Secretary of the Interior Ken Salazar announced the need to
46 develop the LTEMP for Glen Canyon Dam. The Secretary emphasized the inclusion of

1 stakeholders, particularly those in the GCDAMP, in the development of the LTEMP. This
2 decision triggered the NEPA process and the need to conduct public scoping in preparation of
3 this LTEMP DEIS.

4
5 The *Federal Register* NOI to prepare an EIS and hold public scoping meetings was
6 published on July 6, 2011, which marked the beginning of the public comment period. The
7 scoping comment period ended January 31, 2012. A total of six public meetings and one web-
8 based meeting were held in Arizona, Colorado, Nevada, and Utah in November 2011. A total of
9 447 individuals, groups, or organizations submitted scoping comments. Results of the public
10 scoping process are described in the Scoping Summary Report (Reclamation and NPS 2012).

11
12 The affected geographic region and resources of interest and the primary issues of
13 concern to the public identified in scoping are summarized in the following sections. These
14 inputs were used by the lead agencies to formulate a suite of alternative actions that could meet
15 the purpose and need of the proposed action and to guide the comparative analysis of impacts of
16 the alternatives in this DEIS. The alternatives are described in Chapter 2.

17
18 The annual amount of water released under the LTEMP will be determined by the 2007
19 Interim Guidelines until 2026; the guidelines for determining annual releases after that date will
20 be determined under a separate process that, pursuant to the terms of the 2007 Guidelines, is
21 anticipated to begin in 2020 and be subject to public review. This LTEMP DEIS evaluates the
22 effects on resources from the management of monthly, hourly, and daily releases from Glen
23 Canyon Dam under various alternatives.

24 25 26 **1.5.1 Affected Region and Resources**

27
28 In general, the region examined in this DEIS includes the area potentially affected by
29 implementation of the LTEMP (normal and experimental operations of Glen Canyon Dam and
30 non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream
31 to Lake Mead. More specifically, the scope primarily encompasses the Colorado River
32 Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in
33 associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to
34 the western boundary of GCNP. It includes the area where dam operations impact physical,
35 biological, recreational, cultural, and other resources. Portions of GCNRA, GCNP, and LMNRA
36 are included within this area. For certain resources, such as socioeconomics, air quality, and
37 hydropower, the affected region was larger and included areas potentially affected by indirect
38 impacts of the LTEMP. The potentially affected regions for these resources are specifically
39 identified in Chapters 3 and 4. Figure 1-1 portrays the project area in context with the geographic
40 regions of northern Arizona, southwestern Utah, and southern Nevada.

41
42 The primary resources that could be impacted by the proposed action include sediment
43 resources, aquatic and terrestrial ecological resources, historic and cultural resources, resources
44 of importance to American Indian Tribes, recreational resources, and wilderness in the vicinity
45 of the Glen and Grand Canyons, as well as socioeconomic resources, hydropower resources, and
46 air quality.

1 **1.5.2 Impact Topics Selected for Detailed Analysis**
2

3 Topics for analysis in the DEIS were selected on the basis of public scoping comments,
4 joint-lead agency guidance, meetings with Tribes and stakeholders, and relevant laws and
5 regulations. A complete list of issues raised and discussed during scoping is available in the
6 Scoping Summary Report (Reclamation and NPS 2012). The following topics were analyzed in
7 the LTEMP DEIS:
8

- 9 • Water resources, including annual, monthly, and hourly patterns of releases,
10 water temperature, and water quality;
11
- 12 • Sediment resources, including sand and sandbars within the active river
13 channel, and sand that accumulates in the Colorado River delta of Lake Mead;
14
- 15 • Natural processes that support ecological systems within the Colorado River
16 Ecosystem;
17
- 18 • Aquatic resources, including aquatic food base for fishes, nonnative fishes
19 (warmwater, coolwater, and trout), native fishes (including the endangered
20 humpback chub and razorback sucker), and aquatic parasites;
21
- 22 • Riparian vegetation, including Old High Water Zone vegetation, New High
23 Water Zone vegetation, wetlands, and special status plant species;
24
- 25 • Wildlife, including terrestrial invertebrates, amphibians and reptiles, birds,
26 mammals, and special status wildlife species;
27
- 28 • Cultural resources, including archeological resources, historic and prehistoric
29 structures, cultural landscapes, traditional cultural properties, and
30 ethnographic resources important to American Indian Tribes;
31
- 32 • Tribal resources, including vegetation, wildlife, fish, and wetlands, water
33 rights, traditional cultural places, traditional knowledge, and continued access
34 to important resources within Glen and Grand Canyons;
35
- 36 • Recreation, visitor use, and experience as related to fishing, boating, and
37 camping activities in the Colorado River and on Lakes Powell and Mead;
38
- 39 • Wilderness and visitor wilderness experience;
40
- 41 • Hydropower, including the amount and value of hydropower generation at
42 Glen Canyon Dam, marketable electrical capacity, capital and operating costs,
43 and residential electricity bills of electricity customers;
44
- 45 • Socioeconomics, including recreational use values, nonuse economic value,
46 employment and income, and environmental justice;

- 1 • Air quality effects related to changes in Glen Canyon Dam operations,
2 including effects on visibility in the region and air emissions;
3
- 4 • Climate change, including the effects of Glen Canyon operations on
5 greenhouse gas emissions and the effects of climate change on future impacts
6 of Glen Canyon Dam operations; and
7
- 8 • Cumulative impacts of the effects of the proposed action in combination with
9 the effects of past, present, and reasonably foreseeable future projects on the
10 environment.
11

13 **1.5.3 Impact Topics Dismissed from Detailed Analysis**

14
15 The following topics suggested during scoping were dismissed from analysis in the
16 LTEMP DEIS for the reasons stated below:
17

- 18 • *Extirpated Species*. The reintroduction of extirpated species is beyond the
19 scope of the LTEMP DEIS, but was addressed for fish within the NPS
20 Comprehensive Fisheries Management Plan (NPS 2013e).
21
- 22 • *New Infrastructure, Including Temperature Control Devices (TCDs) and*
23 *Sediment Augmentation*. New infrastructure was determined to be outside the
24 scope of the LTEMP DEIS as well as being economically infeasible at this
25 time. Consideration of new infrastructure would require additional
26 engineering analyses, separate NEPA assessments (environmental assessment
27 [EA] or EIS), and potential Congressional authorizations prior to
28 implementation. Research and monitoring related to sediment deposition,
29 erosion, and turbidity, as well as temperature effects on fish, are ongoing and
30 are considered within this plan.
31
- 32 • *Prime and Unique Agricultural Lands*. The Farmland Protection Act of 1981,
33 as amended, requires federal agencies to consider adverse effects on prime
34 and unique farmlands resulting in conversion of these lands to nonagricultural
35 uses. There are no agricultural lands in GCNP or GCNRA, and proposed
36 alternatives would not have direct or indirect effects on downstream
37 agricultural lands. Therefore, this topic is dismissed from further analysis.
38
- 39 • *Land Use in GCNP and GCNRA*. Land use and development of visitor and
40 park facilities in GCNP and GCNRA are managed under the NPS Organic
41 Act, NPS 2006 Management Policies (NPS 2006a), and associated Directors'
42 Orders, GCNP and GCNRA enabling legislation, the Wilderness Act, and
43 other such policies and regulations. None of the proposed alternatives would
44 fundamentally affect land use in GCNP and GCNRA. Therefore, this topic is
45 dismissed from further consideration.
46

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

1.6 ROLE OF ADAPTIVE MANAGEMENT

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

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

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

1.6.1 History of the Existing Adaptive Management Program

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

1 The GCDAMP creates a process for monitoring and assessing the effects of current
2 operations of Glen Canyon Dam on downstream resources and using the results to develop
3 recommendations for modifying operating criteria and other resource management actions. The
4 GCDAMP includes the AMWG, a federal advisory committee that is appointed by the Secretary.
5 The AMWG consists of stakeholders, including federal and state resource management agencies;
6 representatives of the seven basin states; American Indian Tribes; contractors for the purchase of
7 federal hydroelectric power; environmental and conservation organizations; recreational; and
8 other interest groups. The AMWG recommends suitable monitoring and research programs and
9 may make other recommendations to the Secretary as well. The Technical Working Group
10 (TWG) was also proposed in the 1995 EIS and was established to serve as a technical
11 subcommittee to the AMWG. The GCMRC serves as the research branch of the GCDAMP,
12 under the authority of the USGS. Monitoring and research conducted by GCMRC and others
13 since 1996 have improved the understanding of riverine geomorphology and how dam operations
14 can assist in the conservation of natural and cultural resources below the dam. The GCDAMP
15 also includes an external and independent scientific review panel, the science advisors, who
16 serve to peer review research and monitoring programs of the GCDAMP.
17
18

19 **1.6.2 Relationship of Adaptive Management to NEPA and Changes to Operations**

20

21 The 1995 EIS (Reclamation 1995) described adaptive management as the process
22 “whereby the effects of dam operations on downstream resources would be assessed and the
23 results of those resource assessments would form the basis for future modifications of dam
24 operations.” In describing the commitment to adaptive management in the 1996 ROD
25 (Reclamation 1996), the Secretary specified that “any operational changes will be carried out in
26 compliance with NEPA.” In the 2011 NOI (DOI 2011b) that announced the LTEMP process, the
27 DOI specified that a NEPA process would be used to document and evaluate impacts of the
28 alternatives. By articulating and planning for critical uncertainties (Sections 1.7 and 2.1, and
29 Appendix C) upfront, the LTEMP DEIS puts forth an adaptive management plan for the next
30 20 years that is flexible and should allow the experimental, operational, and management
31 changes specified in the LTEMP to proceed without additional NEPA analysis.
32

33 The LTEMP uses an adaptive and experimental framework to refine existing information
34 regarding the effects of dam operations and management actions on affected resources.
35 Information gathered through the adaptive and experimental process may be used to adjust
36 operations within the range of the impacts analyzed in this DEIS.
37
38

39 **1.7 ROLE OF DECISION ANALYSIS IN THE DEIS PROCESS**

40

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

1 While structured decision analysis informed the analysis of the joint leads, it was not the
2 only method by which a preferred alternative is selected. The selection of a preferred alternative
3 was based on the full DEIS analysis and considerations relating to qualitative and quantitative
4 evaluations of impacts. Public comment, socioeconomic considerations, AMWG stakeholder
5 input, and other factors were all considered in this decision.
6

7 The joint-lead agencies partnered with the USGS Patuxent Wildlife Research Center to
8 incorporate formal decision-analysis tools in the LTEMP DEIS. Decision-analysis tools are used
9 to help formally parse out complex problems into manageable pieces, while keeping track of
10 multiple objectives (Gregory and Keeney 2002). Appendix C further describes the decision-
11 analysis tools and methodology as related to the LTEMP DEIS.
12

13 The joint-lead agencies, other DOI agencies, including the BIA, FWS, and USGS, and
14 Argonne technical staff developed performance metrics to evaluate achievement of the resource
15 goals, identified critical uncertainties, and evaluated a preliminary and final set of alternatives in
16 a process that incorporated decision-analysis tools. Performance metrics provide a quantitative,
17 transparent, and objective method to assess the performance of the alternatives against each of
18 the resource goals. Input from some Cooperating Agencies, Tribes, and other stakeholders was
19 used to prepare a final set of performance metrics used in the LTEMP DEIS analysis. Six of the
20 seven Basin States and some of the tribes and other stakeholders elected not to participate in this
21 process for various reasons. The resulting performance metrics are presented in Appendix B.
22

23 Participating stakeholders ranked and weighted the importance of each performance
24 metric according to their preferences for the value of the metric to swing from its lowest to its
25 highest value, representing the range of effects on resources measured by the metric. This
26 process is referred to as “swing-weighting.” The results of swing weighting under structured
27 decision analysis are included in the analysis of alternatives in Chapter 4 and are discussed in
28 further detail in Appendix C.
29

30 While the decision analysis process helped inform the analysis of the joint-lead agencies,
31 it was not used as the method by which a preferred alternative was selected or the only method
32 by which the environmental impacts were fully analyzed. The determination of the preferred
33 alternative was based on the analyses presented in this DEIS. Furthermore, public comment,
34 socioeconomic considerations, AMWG stakeholder input, and other factors were considered in
35 the preparation of this DEIS.
36
37

38 **1.8 HISTORY, LOCATION, AND SETTING**

39 **1.8.1 History and Purpose of Glen Canyon Dam**

40
41
42
43 Glen Canyon Dam, pictured in Figure 1-2, was authorized by CRSPA and completed by
44 Reclamation in 1963 (DOI 2011b). Glen Canyon Dam is the second highest concrete-arch dam
45 in the United States (exceeded only by the Hoover Dam) and rises 710 ft above bedrock within
46 the steep sandstone walls of Glen Canyon. It was constructed to harness the potential of the

1 Colorado River to provide for the water and power needs of millions of people
2 (Reclamation 2008a).

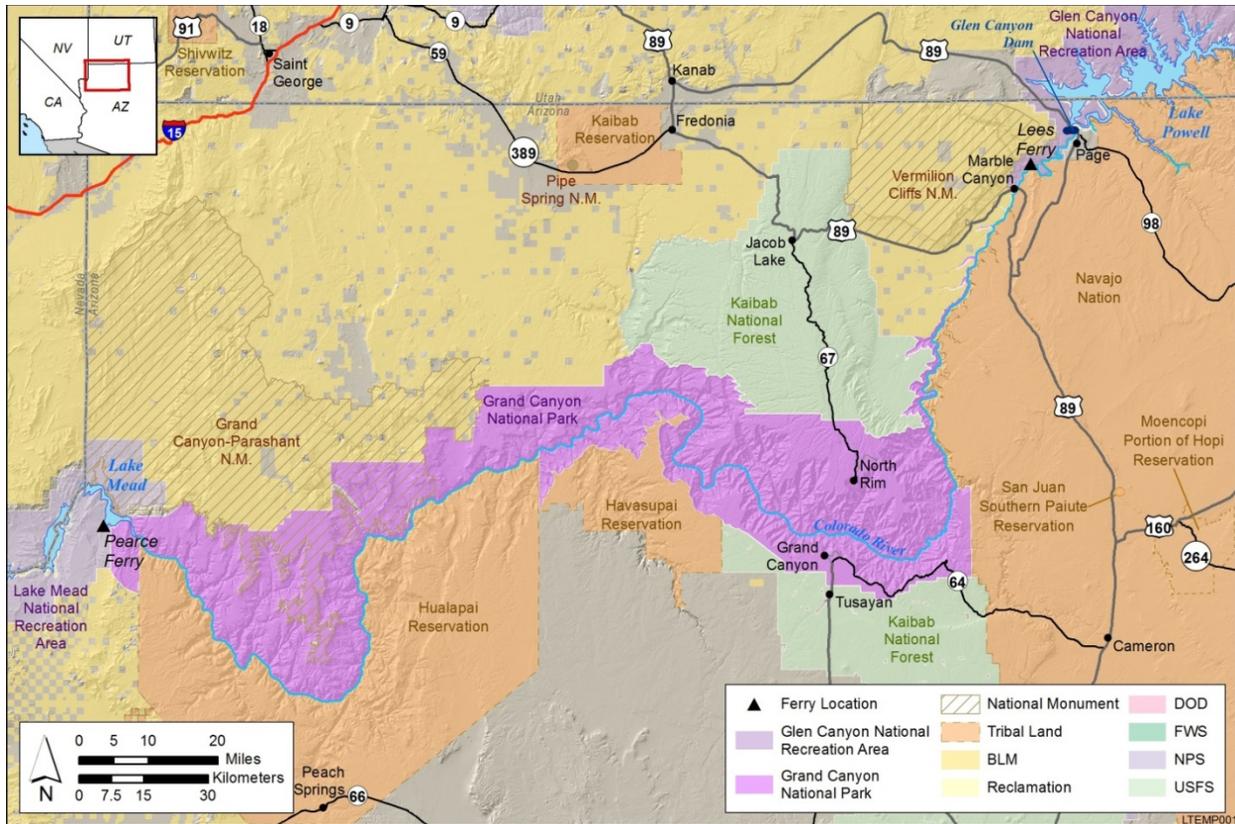
3
4 The CRSPA was enacted for “the comprehensive development of the water resources of
5 the Upper Colorado River Basin, for the purposes, among others, of regulating the flow of the
6 Colorado River, storing water for beneficial consumptive use, making it possible for the States of
7 the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the
8 apportionments made to and among them in the Colorado River Compact and the Upper
9 Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid
10 land, for the control of floods, and for the generation of hydroelectric power, as an incident of the
11 foregoing purposes.” The Glen Canyon Dam is specifically managed to regulate the release of
12 water that allows the Upper Colorado River Basin states of Utah, Colorado, Wyoming, and
13 New Mexico to use their share of the Colorado River, especially during times of drought, while
14 also providing the required delivery of water to the Lower Colorado River Basin states of
15 California, Nevada, and Arizona, as required by the Colorado River Compact of 1922 and
16 subsequent water delivery commitments (DOI 2011b). There is more than 26 million acre-feet
17 (maf) of water storage capacity in Lake Powell, created by Glen Canyon Dam. This stored water
18 has made it possible to successfully weather extended dry periods by sustaining the needs of
19 cities, industries, and agriculture throughout the West (Reclamation 2008a).

20
21 As identified under the CRSPA, another authorized purpose of Glen Canyon Dam is to
22 generate hydroelectric power, which is a clean, renewable, and reliable energy source
23 (DOI 2011b). The hydroelectric power is marketed and delivered by Western to municipalities,
24 rural electric cooperatives, American Indian Tribes, and governmental agencies in Wyoming,
25 Utah, Colorado, New Mexico, Arizona, and Nevada. The dam’s hydroelectric generators, which
26 have a total capacity of 1,320 megawatts, produce about 5 billion kilowatt-hours of hydroelectric
27 power annually to help meet the electrical needs of about 5.8 million customers
28 (Reclamation 2008a). In addition, revenues from production of hydropower fund operations and
29 maintenance of CRSP facilities repay costs for participating projects and help fund many
30 important environmental programs associated with Glen and Grand Canyons
31 (Reclamation 2008a).

32 33 34 **1.8.2 Location of Glen Canyon Dam and LTEMP Affected Area**

35
36 The location of Glen Canyon Dam is shown in the upper right-hand corner of Figure 1-3,
37 which shows the LTEMP affected area from Glen Canyon Dam to Lake Mead. Below Glen
38 Canyon Dam, the Colorado River flows for 15 miles through the GCNRA, which is managed by
39 the NPS and encompasses more than 1.2 million acres of land in northern Arizona and southern
40 Utah (DOI 2011b; NPS 2013c).

41
42 At about 15 mi downstream from the dam, Lees Ferry, Arizona, marks the end of Glen
43 Canyon and the official division between the upper and lower Colorado River
44 (Reclamation 2008b, 2011b). Just downstream from Lees Ferry, the confluence of the Paria
45 River represents the beginning of Marble Canyon and the northern boundary of GCNP. For the



1

2

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

3

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6

7

next 277 mi, the Colorado River flows through the GCNP to Pearce Ferry, which marks the upper reaches of Lake Mead. Lake Mead extends from Pearce Ferry to Hoover Dam.

8

9

10

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

11

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1.8.3 Operation of the Glen Canyon Dam

19

20

21

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

22

23

24

1
2

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

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

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

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

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

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

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

1 The powerplant can release a maximum of about 33,200 cfs of water. Maximum
2 discharges are less when the reservoir is less than full, while MLFF limits maximum flows to
3 25,000 cfs under normal circumstances.
4

5 River outlet works are used when there is a need to release more water than can be passed
6 through the powerplant. River outlet works releases of up to 15,000 cfs are almost always
7 combined with powerplant releases, with a maximum operational release capacity of about
8 48,200 cfs.
9

10 Spillway releases are only used to avoid overtopping of the dam or to lower the level of
11 Lake Powell based on emergency and safety constraints. Such releases bypass both the
12 powerplant and the river outlet works. The reservoir elevation at which the spillways could be
13 accessed is 3,700 ft. The combined capacity of the right and left spillways is 208,000 cfs.
14 Spillway releases are avoided whenever possible; the combined release capacity of all three
15 means of release is about 256,000 cfs.
16
17

18 **1.8.4 History, Purpose, and Significance of the National Park System Units**

19

20 The overarching purpose of the National Park System, as set forth in the NPS's Organic
21 Act, "is to conserve the scenery, natural and historic objects, and wild life in the System units
22 and to provide for the enjoyment of the scenery, natural and historic objects, and wild life in such
23 manner and by such means as will leave them unimpaired for the enjoyment of future
24 generations" (54 U.S.C. § 100101(a)). Each unit of the National Park System is authorized or
25 established by an act of Congress or Presidential proclamation (or sometimes both) to conserve
26 the unit's unique and significant resources. A park's purposes, as described in its enabling
27 legislation or proclamation, are the foundation on which later management decisions are based to
28 conserve resources while providing for the enjoyment of future generations. This mission is
29 further discussed and clarified in *Management Policies 2006* (NPS 2006d). Described below are
30 the park system units relevant to this project: GCNP, GCNRA, and LMNRA.
31
32

33 **1.8.4.1 Grand Canyon National Park**

34

35 GCNP was established as a National Monument in 1908, given National Park status in
36 1919, and recognized as a World Heritage Site in 1979 (NPS 1995). The park attracts nearly
37 5 million visitors annually from the United States and around the world. The purpose of the park
38 "is to be managed to preserve and protect its natural and cultural resources and ecological
39 processes, as well as its scenic, aesthetic and scientific values; and provide opportunities for
40 visitors to experience and understand the environmental interrelationships, resources, and values
41 of the Grand Canyon without impairing the resources" (NPS 1995). Specifically, "the purpose of
42 Grand Canyon National Park is to preserve and protect Grand Canyon's unique geologic,
43 paleontologic, and other natural and cultural features for the benefit and enjoyment of the
44 visiting public; provide the public opportunity to experience Grand Canyon's outstanding natural
45 and cultural features, including natural quiet and exceptional scenic vistas; and protect and
46 interpret Grand Canyon's extraordinary scientific and natural values" (NPS 2010a).

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

2
3 Grand Canyon is one of the planet's most iconic geologic landscapes. During the
4 last 6 million yr, the Colorado River carved Grand Canyon; these same erosional
5 and tectonic processes continually shape the canyon today. Grand Canyon's
6 exposed layers span more than one-third of Earth's history, and record tectonic
7 and depositional environments ranging from mountain building to quiet seas.
8 Taken as a whole, Grand Canyon, with its immense size, dramatic and colorful
9 geologic record exposures, and complex geologic history, is one of our most
10 scenic and scientifically valued landscapes.

11
12 The force and flow of the Colorado River along with its numerous and
13 remarkably unaltered tributaries, springs, and seeps provide plants and animals an
14 opportunity to flourish in this otherwise arid environment. These vital resources
15 represent transmission of local aquatic recharge from high-elevation rims to the
16 arid inner canyon. There are hundreds of known seeps and springs throughout the
17 park, and probably more to be discovered.

18
19 Wilderness landscapes are an important current resource and future preserve. Park
20 boundaries extend beyond canyon walls to include 1,904 sq. miles
21 (1,218,376 acres) of which 94 percent is managed as wilderness. When combined
22 with additional contiguous public and Tribal lands, this area comprises one of the
23 largest U.S. undeveloped areas. Grand Canyon offers outstanding opportunities
24 for visitor experiences including extended solitude, natural quiet, clean air, dark
25 skies, and a sense of freedom from the mechanized world's rigors.

26
27 GCNP is considered one of the finest examples in the world of arid-land erosion
28 (NPS 1995). The park contains several major ecosystems, from the mixed Mohave Desert scrub
29 of the lower canyon to the coniferous forests of the North Rim, and serves as an ecological
30 refuge for relatively undisturbed remnants of dwindling ecosystems (such as boreal forest and
31 desert riparian communities) and numerous rare, endemic, or specially protected
32 (threatened/endangered) plant and animal species, including the California condor (NPS 1995,
33 2013c). The Grand Canyon protects an important cultural history. More than 12,000 years of
34 human occupation have resulted in an extensive archeological record. The park preserves
35 thousands of archeological sites, many of which remain unknown.

36
37 Eleven American Indian Tribes have known ties to the Grand Canyon, and some consider
38 the canyon their original homeland and place of origin. The 11 federally recognized associated
39 Tribes are Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians,
40 Las Vegas Band of Paiute Indians, Moapa Band of Paiute Indians, Navajo Nation, Paiute Indian
41 Tribe of Utah, San Juan Southern Paiute Tribe, Yavapai-Apache Nation, and Zuni Tribe.

42
43 The scenic vistas, qualities, and values of GCNP are internationally recognized and
44 include a variety of landscapes and water features. The Grand Canyon is also known for its
45 natural quiet and opportunities for solitude. The natural, cultural, and scenic qualities of the

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

3 4 5 **1.8.4.2 Glen Canyon National Recreation Area**

6
7 The GCNRA was established by Congress in 1972 and occupies approximately
8 1,255,000 ac of northern Arizona and southeastern Utah adjacent to Lake Powell (NPS 1979).
9 Congress directed NPS to manage the GCNRA so as to provide for public outdoor use and
10 enjoyment of Lake Powell and lands adjacent thereto in the States of Arizona and Utah and to
11 preserve scenic, scientific, and historic features contributing to public enjoyment of the area
12 (Public Law [P.L.] 92-593). In 2012, GCNRA attracted approximately 2 million visitors
13 (NPS 2014f).

14
15 The GCNRA ecosystem typifies the Colorado Plateau, supporting habitat for a diverse
16 range of plants and animals. The region is arid to semi-arid, and the ecosystem is complex and
17 often fragile (NPS 1979). Several rare and federally listed plant and animal species are found in
18 the GCNRA: Navajo sedge, Jones cycladenia, the northern leopard frog, Colorado pikeminnow,
19 humpback chub, and razorback sucker (NPS 2013b).

20
21 Glen Canyon has been occupied periodically by humans from about 11,500 years ago
22 through the present (NPS 1979, 2013a). Several different prehistoric cultures and current Native
23 American groups are represented in the cultural history of Glen Canyon, and the recreation area
24 occupies a cultural interface zone, where different groups historically came into contact with one
25 another (NPS 2013a). In the late 1800s, the crossing at Lees Ferry and the Hole-in-the-Rock trail
26 became important points on the migration route of Mormon settlers moving westward
27 (NPS 1979).

28 29 30 **1.8.4.3 Lake Mead National Recreation Area**

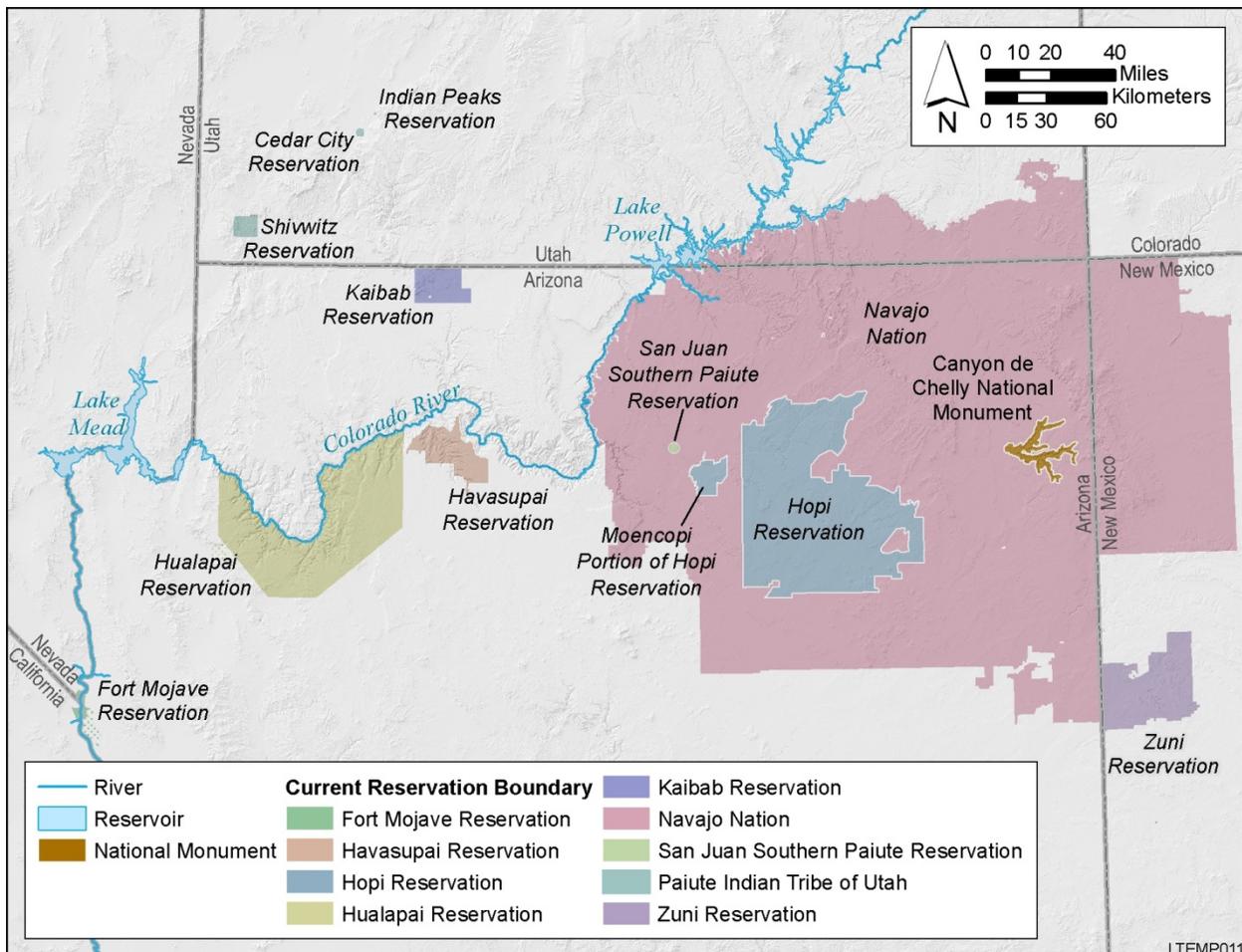
31
32 The LMNRA was established on October 8, 1964. Its purpose is to provide diverse public
33 recreation, benefit, and use on Lakes Mead and Mohave and surrounding lands in a manner that
34 preserves the ecological, geological, cultural, historical, scenic, scientific, and wilderness
35 resources of the park. LMNRA includes two reservoirs, Lakes Mead and Mohave, along 140 mi
36 of the former Colorado River from the southern tip of Nevada to the northwest corner of
37 Arizona. It is the fourth largest unit of the national park system outside the state of Alaska.
38 Approximately 60% of the park is located in Arizona and 40% is located in Nevada
39 (NPS 2002c).

40
41 LMNRA offers dramatic scenery and a diverse array of land- and water-based
42 recreational opportunities in close proximity to several large urban centers of the southwestern
43 United States. With more than 6 million visitors each year, the park supports some of the
44 nation's highest levels of water recreational and backcountry use and is an integral component of
45 the region's economy (NPS 2002c).

1 Situated in the northeastern Mojave Desert near the interface with the Great Basin Desert
 2 to the north and the Sonoran Desert to the south, LMNRA preserves a great diversity of
 3 biological resources, intact habitat, and ecological connectivity in the region, including many
 4 threatened and endangered species and rare natural communities. It showcases a remarkable
 5 collection of geological and paleontological features spanning more than 1.7 billion years of
 6 earth history (USGS 2014a). The diversity of cultural resources found at LMNRA—both on land
 7 and submerged—remains as evidence of a 10,000-year continuum of human history in the region
 8 (NPS 2013f). LMNRA also includes vast backcountry and wilderness lands, including nine
 9 separate designated wilderness areas that serve to preserve ecological resources and processes
 10 and provide exemplary opportunities for primitive recreation and desert solitude (NPS 2002c).
 11
 12

13 1.8.5 Tribal Lands

14 Numerous laws and treaties have established Indian reservations within or adjacent to the
 15 project area (see Figure 1-4). Traditional territory and traditional use lands extend well beyond
 16 the project area (see Figure 1-4). Traditional territory and traditional use lands extend well beyond
 17
 18



19

20 **FIGURE 1-4 Indian Reservations within or Adjacent to the LTEMP DEIS Project Area**

1 these boundaries. The following sections summarize laws, treaties, and traditional use areas of
2 Tribes with ancestral, spiritual, religious, or economic ties to the project area. Tribal connections
3 to resources in and around the Colorado River and the canyons are described in Chapter 3.
4
5

6 **1.8.5.1 Navajo Nation**

7

8 The Navajo Indian Reservation was established by the Treaty of June 1, 1868
9 (15 Stat. 667). Between 1868 and 1918 various executive orders added lands to, or removed
10 lands from, the reservation. The Act of May 25, 1918 (40 Stat. 561, 570), prohibited the creation
11 of, or any additions to, Indian reservations in New Mexico and Arizona “except by Act of
12 Congress.” Congress added land to the Navajo Indian Reservation by the Act of May 23, 1930
13 (46 Stat. 378), amended by the Act of February 21, 1931 (46 Stat. 378), and the Act of March 1,
14 1933 (47 Stat. 1418). The Act of June 14, 1934 (48 Stat. 960), describes the exterior boundaries
15 of the 17.6-million-ac reservation in Arizona, subject to various exclusions and conditions set out
16 in the act.
17

18 The traditional Navajo homeland, or *Dinétaah*, is bounded by four sacred mountains:
19 *Siss Naajinii* (Blanca Peak, near Alamosa, Colorado) on the east; *Tsoo Dzil* (Mount Taylor near
20 Grants, New Mexico) on the south; *Dook’o’oosliid* (San Francisco Peaks near Flagstaff,
21 Arizona) on the west; and *Dibé Ntsaa* (La Plata Mountains near Durango, Colorado) on the
22 north. Traditional use areas extend well beyond this boundary (Reclamation 1995).
23
24

25 **1.8.5.2 Hualapai**

26

27 The Hualapai Reservation was established by Executive Orders of January 4, 1883;
28 June 2, 1911; May 29, 1912; and July 18, 1913. The reservation encompasses 992,463 ac just
29 south of the Colorado River. The reservation borders the river corridor for approximately 108 mi
30 from approximately river mile (RM) 164.5 to RM 273.5 (NPS 2006b).
31

32 Hualapai traditional territory is bounded by the Colorado River from the Big Bend near
33 Hoover Dam-Lake Mead to the Little Colorado River on the north, the San Francisco Peaks on
34 the east, the Bill Williams and Santa Maria Rivers on the south, and the Colorado River from its
35 confluence with the Bill Williams River to Lake Mead on the west (Reclamation 1995).
36
37

38 **1.8.5.3 Havasupai**

39

40 The Havasupai Indian Reservation was established by the Executive Orders of June 8 and
41 November 23, 1880, and March 31, 1882, and expanded by the Act of March 4, 1944
42 (58 Stat. 110), and the Grand Canyon Enlargement Act (88 Stat. 2089, 1975). In 1975, the Grand
43 Canyon National Park Enlargement Act restored 185,000 ac to the Havasupai Reservation and
44 identified 95,300 ac of traditional use lands within GCNP that were made available for
45 traditional Havasupai practices.
46

1 The Havasupai Reservation consists of 188,077 ac of canyon and plateau along the
2 western portion of the Grand Canyon's south rim. Additional traditional use lands are located
3 within GCNP north of the reservation from the plateau to the Colorado River and extend from
4 approximately RM 116 to RM 165 (Havasupai 2012).
5

6 The Indian Claims Commission determined in 1968 that as of 1880, the Havasupai Tribe
7 exclusively occupied, as their original territory, the land on the Coconino Plateau bounded by the
8 mid-stream of the Colorado River on the north, the Hualapai Reservation on the west, south to
9 the Trinity Mountain, Mount Floyd and easterly to Sitgreaves Mountain, north to Mount
10 Kendricks and along the Little Colorado River on the east to the Colorado River.
11

12 The Grand Canyon Enlargement Act of 1975 replaced a portion of the tribal lands,
13 permitted the traditional uses of park lands, and placed restrictions on the use of portions of the
14 Havasupai Reservation within GCNP in order to preserve the scenic and natural values of the
15 park (16 USC 228i(b)(7)).
16
17

18 **1.8.5.4 Southern Paiute Tribes** 19

20 The Southern Paiute Tribes that have ties to the region and who are most directly tied to
21 the project area include the Kaibab Band of Paiute Indians; the Paiute Indian Tribe of Utah,
22 which consists of five bands of Southern Paiute (Cedar Band, Indian Peaks Band, Kanosh Band,
23 Koosharem Band, and Shivwits Band); and the San Juan Southern Paiute. The Kaibab Band of
24 Paiute Indians and the Paiute Indian Tribe of Utah are also members of the Southern Paiute
25 Consortium. The Kaibab Band represents the consortium in matters pertaining to Glen Canyon
26 Dam and Colorado River management.
27

28 The Kaibab Band of Paiute Indians Reservation was established by the Executive Orders
29 of June 11, 1913, and July 17, 1917. The reservation is located approximately 50 mi north of the
30 Grand Canyon. The reservation encompasses approximately 121,000 ac and includes five Tribal
31 villages and two non-Indian communities (Kaibab Paiute 2013).
32

33 The Paiute Indian Tribe of Utah Reservation was established on April 3, 1980, by an Act
34 of Congress (94 Stat. 317, 1980) and consists of 10 separate land parcels located in 4
35 southwestern Utah counties, covering 33,709 ac (PITU 2013).
36

37 The San Juan Southern Paiute were given 5,400 ac of land within the Navajo Reservation
38 boundary when their leaders signed a treaty with the Navajo Nation on May 20, 2000.
39 Approximately 5,100 ac of this land is located near Tuba City, Arizona, with the remaining
40 300 ac located just south of Lake Powell (NPS 2013d).
41

42 The traditional lands of the Southern Paiute people are bounded by more than 600 mi of
43 the Colorado River, extending from the Kaiparowits Plateau in southern Utah to Blythe,
44 California (Bullets et al. 2012). These lands extend from the Colorado River northward,
45 inclusive of the Grand and Glen Canyons, into Beaver County, Utah, and from the Escalante
46 River drainage on the east within GCNRA to Death Valley on the west, including the Virgin

1 River drainage, the Muddy River drainage, and the area around present-day Las Vegas, Nevada
2 (ICC 1965).
3
4

5 **1.8.5.5 Hopi**

6
7 The original Hopi Reservation was established by the Executive Order of December 16,
8 1882, as a 1×1 degree latitude/longitude rectangular region. Subsequent partitioning of this
9 original reservation area between the Hopi Tribe and Navajo Nation has resulted in a smaller
10 reservation area, encompassing about 1.5 million ac in parts of Coconino and Navajo Counties,
11 Arizona. There are 11 main Hopi villages within the central portion of the Hopi Reservation and
12 two additional villages located to the west at Moencopi, on a non-contiguous portion of the Hopi
13 Reservation (Figure 1-4).
14

15 The Hopi people view their traditional homeland as much larger than the current
16 reservation. It encompasses an area running from near the confluence of the San Juan and
17 Colorado Rivers in the north, southwest to the area of the Havasupai Reservation, southward past
18 Williams and out to the Mogollon Rim in the south, and eastward to the Lupton area on the
19 Arizona–New Mexico border. Even this area is but a small portion of the lands occupied by the
20 ancestors of the Hopi people, which include portions of Colorado, Utah, Arizona, and
21 New Mexico.
22
23

24 **1.8.5.6 Pueblo of Zuni**

25
26 The Zuni Indian Reservation was established by the Executive Orders of March 16, 1877,
27 May 1, 1883, and March 3, 1885, and was expanded by the Proclamation of November 30, 1917
28 (40 Stat. 1723); the Congressional Act of June 20, 1935 (49 Stat. 393); the Executive Order of
29 August 13, 1949; and the Congressional Act of March 16, 1962 (76 Stat. 33). The Pueblo of Zuni
30 is located approximately 150 mi west of Albuquerque, New Mexico, and encompasses
31 approximately 450,000 ac (Pueblo of Zuni 2013). In addition to the lands established by
32 Executive Orders and Presidential proclamation, two additional non-contiguous areas are
33 included in the Zuni Reservation: the Zuni Salt Lake (1 mi²) added in 1978 and Kolhu'wala:wa
34 (Zuni Heaven) in Arizona consisting of 14 mi² added on August 28, 1984.
35

36 The traditional territory of the Zuni Tribe is bounded by the San Francisco Peaks on the
37 northwest corner and by portions of the Little Colorado River and Pueblo Colorado Wash on the
38 far northern boundary. The view of Pueblo of Zuni is that traditional use extends considerably
39 beyond the traditional territorial boundaries and includes GCNP and GCNRA
40 (Reclamation 1995; Dongoske 2012). It also should be noted that the Zunis are considered an
41 Indian Tribe of Arizona.
42
43

1 **1.8.5.7 Fort Mojave**
2

3 The Fort Mojave Indian Reservation was established through the Executive Orders of
4 December 1, 1910, and February 2, 1911. The reservation is located along the Colorado River,
5 near Needles, California, and encompasses 42,000 ac covering Mohave County, Arizona; Clark
6 County, Nevada; and San Bernardino County, California (Fort Mojave Indian Tribe 2012).
7

8 Traditional Mojave territory encompasses most of the Mojave Desert in the State of
9 California, from the Whipple Mountains, the Turtle Mountains, the Granite Mountains, the Eagle
10 Mountains, the Little San Bernardino Mountains, and the San Bernardino Mountains in the
11 south, west to the San Gabriel and Tehachapi Mountains, north to Granite and Soda Lakes and
12 the Providence Mountains and Paiute Valley in the State of Nevada, to the Black, Buck, and
13 Mojave Mountains to the east in the State of Arizona (CSRI 2002 [U.S. Court of Claims 1950-
14 1960: Docket 283]).
15
16

17 **1.9 LAWS AND REGULATIONS RELATED TO OPERATIONS OF GLEN CANYON**
18 **DAM AND PARK MANAGEMENT**
19

20 The following lists of laws, regulations, and treaties are presented here to provide context
21 for the management of the Colorado River because they must be complied with for operation of
22 Glen Canyon Dam and for park management, and may or may not specifically apply to this
23 action. Nothing in this DEIS is intended to interpret the authorities listed below.
24
25

26 **1.9.1 Environmental Laws and Executive Orders**
27

- 28 • Bald and Golden Eagle Protection Act of 1940, as amended 1962
29 (16 USC 668c)
- 30
- 31 • Clean Air Act of 1970 (33 USC 1251 et seq.)
- 32
- 33 • Clean Water Act of 1972 (33 USC 1251 et seq.)
- 34
- 35 • Endangered Species Act of 1973 (16 USC 1531-1544, 87 Stat. 884)
- 36
- 37 • E.O. 11514, “Protection and Enhancement of Environmental Quality,” as
38 amended by E.O. 11991, “Relating to Protection and Enhancement of
39 Environmental Quality” (U.S. President 1970)
- 40
- 41 • E.O. 11988, “Floodplain Management” (U.S. President 1977a)
- 42
- 43 • E.O. 11990, “Protection of Wetlands” (U.S. President 1977b)
- 44
- 45 • E.O. 13112, “Invasive Species” (U.S. President 1999)
- 46

- 1 • E.O. 13186, “Responsibilities of Federal Agencies to Protect Migratory Birds”
2 (U.S. President 2001)
3
- 4 • Fish and Wildlife Coordination Act of 1934 (16 USC 661 et seq.)
5
- 6 • Migratory Bird Treaty Act of 1918, as amended 2008 (16 USC 703)
7
- 8 • National Environmental Policy Act of 1969, as amended (42 USC 4321
9 et seq.)
10
- 11 • National Park Service Organic Act of 1916 (16 USC 1-4, 22, and 43, as
12 amended)
13
- 14 • Redwoods National Park Expansion Act of 1978 (Redwoods Amendment)
15 (16 USC 1a-1)
16
- 17 • Wild and Scenic Rivers Act of 1968 (16 USC 1271 et seq.)
18
- 19 • Wilderness Act of 1964 (16 USC 1131–1136)
20

21 22 **1.9.2 Cultural/Historical Laws and Executive Orders**

- 23 • Antiquities Act of 1906 (16 USC 431–433)
24
- 25 • Archaeological and Historic Preservation Act of 1974 (16 USC 469 et seq.)
26
- 27 • Archaeological Resources Protection Act of 1979 (16 USC 470 et seq.,
28 P.L. 96-95)
29
- 30 • E.O. 11593, “Protection and Enhancement of the Cultural Environment”
31 (U.S. President 1971)
32
- 33 • Historic Sites, Buildings, and Antiquities Act of 1935 (16 USC 461 et seq., as
34 amended by P.L. 89-249)
35
- 36 • National Historic Preservation Act of 1966 (54 USC 300101 et seq., P.L. 89-
37 665)
38

39 40 41 **1.9.3 American Indian and Tribal Consultation Laws and Executive Orders**

- 42 • American Indian Religious Freedom Act of 1978 (P.L. 95-431, 92 Stat. 469,
43 42 USC 1996)
44
- 45 • E.O. 13007, “Indian Sacred Sites” (U.S. President 1996)
46
47

- 1 • E.O. 13175, “Consultation and Coordination with Indian Tribal Governments”
2 (U.S. President 2000)
3
- 4 • Native American Graves Protection and Repatriation Act of 1990
5 (P.L. 101-601, 104 Stat. 3048, 25 USC 3001 et seq.)
6
7

8 **1.9.4 Law of the River**

9
10 The treaties, compacts, decrees, statutes, regulations, contracts, and other legal
11 documents and agreements applicable to the allocation, appropriation, development, exportation,
12 and management of the waters of the Colorado River Basin are often referred to as the Law of
13 the River. There is no single, universally agreed upon definition of the Law of the River, but it is
14 useful as a shorthand reference to describe this longstanding and complex body of legal
15 agreements governing the Colorado River. Documents generally considered to be part of the Law
16 of the River include those listed in Table 1-2.
17
18

19 **1.10 RELATED ACTIONS**

20
21 Numerous ongoing and completed plans, policies, actions, and initiatives are related to
22 the operation of the Glen Canyon Dam and Colorado River with respect to the proposed federal
23 action analyzed in this DEIS. Reclamation and NPS have identified documents that would assist
24 the reader in understanding the issues analyzed in this process and underscore the importance of
25 collaboration among agency and stakeholder participants.
26
27

28 **1.10.1 Biological Opinions**

- 29
30 • Final Biological Opinion for the Proposed Adoption of Colorado River
31 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for
32 Lake Powell and Lake Mead (FWS 2007a).
33
- 34 • Final Biological Opinion on the Operation of Glen Canyon Dam, including
35 High-Flow Experiments and Nonnative Fish Control (FWS 2011c). This
36 replaced former Biological Opinions from 1995 to 2009.
37
- 38 • Final Biological Opinion on the Comprehensive Fisheries Management Plan,
39 Coconino and Mohave Counties, Arizona (FWS 2013a).
40
41

42 **1.10.2 Environmental Impact Statements and Related Documents**

43
44 **Operation of Glen Canyon Dam: Environmental Impact Statement and Record of**
45 **Decision (Reclamation 1996).** As discussed in the Introduction, Glen Canyon Dam currently
46 operates under provisions of the EIS completed in 1995 (Reclamation 1995). The Secretary

1 **TABLE 1-2 Selected Documents Included in the Law of the River^a**

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

^a Years in italics indicate amendments or related actions.

Source: Reclamation (2007b).

1 accepted the recommendation of the 1995 EIS and signed the 1996 ROD (Reclamation 1996)
2 that selected MLFF as the operating system for the dam. The flow parameters of MLFF are
3 presented in Section 1.8.3 of this DEIS.
4

5 A component of the final Glen Canyon Dam EIS (Reclamation 1995) and the
6 environmental commitments identified in the 1996 ROD (Reclamation 1996) was the
7 implementation of a Programmatic Agreement regarding operations of the Glen Canyon Dam.
8 This agreement, along with subsequent monitoring and remedial action plans and the 2007
9 Comprehensive Treatment Plan, set a strategy for long-term management of archaeological sites
10 affected by the operations of Glen Canyon Dam. In addition, separate, action-specific
11 Memoranda of Agreement were established among the signatories to the agreements, primarily
12 Reclamation, NPS, Arizona State Historic Preservation Office, and affiliated Tribes for actions
13 related to the High Flow Experimental Protocol EA (Reclamation 2011b) and the Nonnative Fish
14 Control EA (Reclamation 2011a).
15

16 **Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated**
17 **Operations for Lake Powell and Lake Mead (Reclamation 2007b).** In 2005, spurred by a
18 multi-year drought, decreasing system storage, and growing demands for Colorado River water,
19 the Secretary directed Reclamation to develop additional strategies for improving the
20 coordinated management of the reservoirs of the Colorado River system. In response,
21 Reclamation began to develop and adopt interim operational guidelines that would address the
22 operation of Lake Powell and Lake Mead during drought and low-reservoir conditions. Adopted
23 in 2007, these Interim Guidelines would be used each year (through 2025 for water supply
24 determinations and through 2026 for reservoir operating decisions) in implementing the LROC
25 for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. This
26 ROD did not modify the authority of the Secretary to determine monthly, daily, hourly, or
27 instantaneous releases from Glen Canyon Dam.
28

29 The completed Interim Guidelines determine the availability of Colorado River water for
30 use in the Lower Basin, on the basis of Lake Mead's water surface elevation, as a way to
31 conserve reservoir storage and provide water users and managers with greater certainty regarding
32 the reduction of water deliveries during drought and other low-reservoir conditions. The Interim
33 Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing
34 releases and conserved amounts on predetermined levels in both reservoirs, which would
35 minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin.
36 In addition, the Interim Guidelines established a mechanism for storing and delivering conserved
37 water from Lake Mead, referred to as Intentionally Created Surplus, intended to minimize the
38 severity and likelihood of potential future shortages.
39

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

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

10
11 **General Management Plan for Grand Canyon National Park (NPS 1995).** This plan
12 guides the management of resources, visitor use, and general development at the park over a
13 10- to 15-year period. The primary purpose of the plan is to provide a foundation from which to
14 protect park resources while providing for meaningful visitor experiences. A secondary purpose
15 is to encourage compatible activities on adjacent lands so as to minimize adverse effects on the
16 park.

17
18 **Backcountry Management Plan, Grand Canyon National Park, Arizona (NPS 1988).**
19 This plan defines the primary policies that manage visitor use and resource protection for the
20 undeveloped areas of GCNP. GCNP has started work on a Backcountry Management Plan and
21 EIS. The park’s existing Backcountry Management Plan is being updated to comply with current
22 NPS laws and policies and the park’s 1995 General Management Plan. Once completed, the
23 revised Backcountry Management Plan will guide management decisions regarding the park’s
24 backcountry and wilderness resources into the future.

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

33
34 **Glen Canyon National Recreation Area General Management Plan—Final**
35 **Environmental Impact Statement (NPS 1979).** This plan and wilderness recommendation lays
36 out proposals for meeting four levels of management objectives for GCNRA, ranging from
37 general to specific. The first-level objective is to manage GCNRA to maximize its recreational
38 enjoyment. Objective levels 2 through 4 address increasingly specific objectives, including those
39 for cultural, Tribal, mineral, and grazing resources and management of the reservoir. The plan
40 presents a management zoning proposal to divide GCNRA into four management zones: natural,
41 recreation and resource utilization, cultural, and development.

1 **1.10.3 Environmental Assessments and Related Documents**
2

3 **Nonnative Fish Control Environmental Assessment (Reclamation 2011a).** In this
4 assessment, Reclamation proposed to conduct research, monitoring, and specific actions to
5 control nonnative fish in the Colorado River downstream from Glen Canyon Dam in an effort to
6 help conserve native fish. The purpose of the action was to minimize the negative impacts of
7 competition and predation on an endangered fish, the humpback chub. The action was needed
8 because competition and predation by nonnative fishes, particularly rainbow trout and brown
9 trout, may be contributing to a reduction in survival and recruitment of young humpback chub
10 and threatening the potential recovery of the species. Rainbow trout and brown trout are not
11 native to the Colorado River Basin and have been introduced into the region as sport fish. The
12 Finding of No Significant Impact (FONSI) (Reclamation 2012b) was signed in May of 2012.
13

14 **High-Flow Experiment Protocol Environmental Assessment (Reclamation 2011b).**
15 This experimental protocol was developed following analysis of a series of high-flow
16 experimental releases. The protocol is intended to improve conservation of limited sediment
17 resources in the Colorado River below Glen Canyon Dam. The FONSI (Reclamation 2012a) was
18 signed in May of 2012.
19

20 **Environmental Assessment, Comprehensive Fisheries Management Plan for Grand**
21 **Canyon National Park and Glen Canyon National Recreation Area (NPS 2013e).** The NPS
22 will implement a CFMP, in coordination with the Arizona Game and Fish Department
23 (AZGFD), the FWS, Reclamation, and the USGS GCMRC, for all fish-bearing waters in GCNP
24 and GCNRA below Glen Canyon Dam. The intent of the CFMP is to maintain a thriving native
25 fish community within GCNP and a highly valued recreational rainbow trout fishery in the Glen
26 Canyon reach of GCNRA. NPS released a FONSI on December 9, 2013, for the CFMP.
27

28 **Environmental Assessment and Assessment of Effect, Exotic Plant Management**
29 **Plan Grand Canyon National Park, Arizona (NPS 2009a).** GCNP proposed using integrated
30 pest management techniques to control and contain exotic plant species within park boundaries.
31 Exotic plant species displace natural vegetation and consequently affect long-term health of
32 native plant and animal communities.
33

34
35 **1.10.4 Other Actions, Programs, Plans, and Projects**
36

37 **Colorado River Basin Salinity Control Program (Reclamation 2014c).** The Colorado
38 River and its tributaries provide municipal and industrial water to about 27 million people and
39 irrigation water to nearly 4 million ac of land in the United States. The threat of salinity is a
40 major concern in both the United States and Mexico. In June 1974, Congress enacted the
41 Colorado River Basin Salinity Control Act (P.L. 93-320), which directed the Secretary to
42 proceed with a program to enhance and protect the quality of water available in the Colorado
43 River for use in the United States and Republic of Mexico.
44

45 **Lake Powell Pipeline Project (WCWCD 2012).** Washington, Kane, and Iron Counties
46 in Utah are pursuing the construction of a pipeline that would run from Lake Powell, near Glen

1 Canyon Dam, through Kane County, to Sand Hollow Reservoir, which is located approximately
2 10 mi east of St. George. The pipeline would then run parallel to Interstate 15 into Iron County.
3 The pipeline would be 158 mi long and bring 70,000 ac-ft of water to Washington County,
4 10,000 ac-ft to Kane County, and 20,000 ac-ft to Iron County.
5

6 **Final Wilderness Recommendation, Grand Canyon National Park, 2010 Update.**

7 The 1980 Final Wilderness Recommendation submitted to the DOI includes 1,143,918 ac
8 proposed for wilderness designation, and includes 26,461 ac as potential wilderness pending the
9 resolution of boundary and motorized boat use issues. The Colorado River was identified as
10 potential wilderness. In 2010, NPS conducted internal reviews and included refinements to the
11 proposed wilderness acreage estimates. All refinements were consistent with the intent of the
12 original document submitted to the DOI in 1980.
13

14 **Grand Canyon National Park Foundation Statement for Planning and Management**
15 **(NPS 2010a).** The Foundation Statement provides a base for future planning, as required by
16 NPS, to help guide park management. The Foundation Statement summarizes fundamental
17 resources and values critical to maintaining Grand Canyon’s natural, cultural, and experiential
18 value into the future. Because this Foundation Statement is based on laws and policies that define
19 GCNP and its mission, the Statement should remain relatively unchanged.
20

21 **Glen Canyon National Recreation Area and Rainbow Bridge National Monument**
22 **Foundation Document for Management and Planning (NPS 2014i).** The Foundation
23 Statement provides a base for future planning, as required by NPS, to help guide park
24 management. The Foundation Statement summarizes fundamental resources and values critical
25 to maintaining Glen Canyon and Rainbow Bridge’s natural, cultural, and experiential value into
26 the future. Because this Foundation Statement is based on laws and policies that define GCNRA
27 and its mission, the Statement should remain relatively unchanged.
28

29 **Management and Control of Tamarisk and Other Invasive Vegetation at**
30 **Backcountry Seeps, Springs, and Tributaries in Grand Canyon National Park (NPS 2008).**
31 Grand Canyon National Park’s backcountry seeps, springs, and tributaries of the Colorado River
32 are among the most pristine watersheds and desert riparian habitats remaining in the coterminous
33 United States. This report contains the details from the invasive plant control and monitoring
34 efforts completed for one phase (Phase II-B) of the three-phase project. Reports for the previous
35 two phases are also available on the NPS website.
36

37 **Strategic Plan for Glen Canyon National Recreation Area and Rainbow Bridge**
38 **National Monument FY2007–FY2011 (NPS 2006c).** This 5-year Strategic Plan has been
39 written for GCNRA and Rainbow Bridge National Monument (NM). Because Rainbow Bridge
40 NM is administered by GCNRA, this strategic plan covers both units of the NPS.
41

42 **Grand Canyon National Park Resource Management Plan (NPS 1997).** The purpose
43 of the Resource Management Plan was to provide long-term guidance and direction for the
44 stewardship of the natural, cultural, and recreational resources of GCNP.
45

2 DESCRIPTION OF ALTERNATIVES

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

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

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

- Decommission Glen Canyon Dam
- Fill Lake Mead first
- Grand Canyon first
- Maximum powerplant capacity operations
- Modified low fluctuating flows
- Naturally patterned flows

- 1 • Run-of-the-river
- 2
- 3 • Species community and habitat-based alternative
- 4
- 5 • Stewardship alternative
- 6
- 7 • 12-year experiment of two steady-flow alternatives
- 8
- 9 • Year-round steady flows

10
11 These concepts were considered by Reclamation and NPS for detailed analysis during the
12 alternative development process. In some cases, these were included as an LTEMP alternative, or
13 elements were incorporated within one of the alternatives. In other cases, the concept was
14 eliminated from consideration or further analysis because it did not meet the purpose, need, or
15 objectives of the proposed action; clearly violated existing laws or regulations; or lacked enough
16 specifics to be developed into a full and unique alternative (Section 2.3).

17
18 In addition to these submitted alternative concepts, the public identified a variety of
19 specific elements that should be considered for inclusion in LTEMP DEIS alternatives. These
20 elements were considered for inclusion by the joint-lead agencies as they developed LTEMP
21 alternatives. Elements considered but not analyzed in detail are presented in Section 2.4.

22 23 24 **2.1 DEVELOPMENT OF ALTERNATIVES**

25
26 The alternative development process began with identification of the proposed action
27 (i.e., development of an LTEMP), purpose and need of the LTEMP, and the resource goals and
28 objectives of the LTEMP (Sections 1.1, 1.2, and 1.4, respectively). Once these items were
29 defined, NPS and Reclamation worked to develop a set of alternatives that represented the full
30 range of reasonable experimental and management actions; met the purpose, need, and objectives
31 of the proposed action; and were within the constraints of existing laws, regulations, and existing
32 decisions and agreements.

33
34 Alternative operations that either used different operational strategies (e.g., consistent
35 monthly release pattern or condition-dependent release pattern) or had different primary
36 objectives (e.g., native fish, sediment, or restoration of a more natural flow pattern) were
37 developed and refined. In developing alternatives for detailed analysis, NPS and Reclamation
38 considered and evaluated concepts identified by the public during scoping, alternatives that had
39 been identified for the cancelled Long-Term Experimental Plan (LTEP) Environmental Impact
40 Statement (EIS), and alternatives that had been identified in several efforts led by the Glen
41 Canyon Dam Adaptive Management Program (GCDAMP) (USGS 2006, 2008).

42
43 An “alternative screening tool” was developed by the LTEMP DEIS team to aid in the
44 development of alternatives by providing preliminary analysis of alternative concepts; it
45 subsequently helped to identify specific operational characteristics of alternatives (e.g., monthly
46 volumes, daily ranges) that would meet the purpose, need, goals, and objectives of the proposed

1 action. This spreadsheet tool used a set of simple models to produce a screening-level appraisal
2 of the impacts of alternatives on flow, sediment (sand) transport, water temperature, humpback
3 chub (*Gila cypha*) growth, trout recruitment, and hydropower value (generation and capacity).
4

5 The screening tool was used primarily for rapid prototyping of alternative concepts, and
6 to supplement a full analysis of impacts. It was also used to evaluate potential modifications to
7 Alternative D after full modeling was completed. The screening tool focused on the effects of
8 monthly, daily, and hourly flow patterns in single years rather than the effects of multiple years.
9 The screening tool produced:

- 10 • Daily, monthly, and annual estimates of sediment transport (metric tons/year)
11 based on Figure 4a from Rubin et al. (2002);
12
- 13 • Mean monthly temperature at river mile (RM) 61 (confluence with the Little
14 Colorado River) and RM 225 based on Wright, Anderson et al. (2008);
15
- 16 • Mean monthly and annual total growth rates for humpback chub at RM 61 and
17 225 based on a growth-temperature regression in Robinson and Childs (2001);
18
- 19 • Annual estimates of trout recruitment based on an empirical relationship
20 developed by Korman et al. (2012);
21
- 22 • Daily, monthly, and annual estimate of hydropower value based on the value
23 of hydropower (\$/MWh) at different hours of the day and using a conversion
24 factor for cfs to MWh using information from the GTMax model
25 (Palmer et al. 2007); and
26
- 27 • Annual estimate of hydropower capacity based on the value of power
28 generated by maximum daily flows during the peak power month of August.
29
30

31 Several iterations of preliminary draft alternative concepts developed by NPS and
32 Reclamation were presented to the Cooperating Agencies and other stakeholders in workshops
33 and webinars to explain the alternative development process, describe proposed alternative
34 characteristics, and solicit feedback. Workshops included (1) a facilitated public workshop on
35 April 4 and 5, 2012; (2) Cooperating Agency and Tribal meetings on August 10, 2012; (3) Tribal
36 workshops on March 14, 2013; (4) a stakeholder workshop on August 5–7, 2013;
37 (5) a stakeholder workshop on March 31–April 1, 2014; and (6) a stakeholder webinar on
38 December 3, 2015. There were also monthly calls with Cooperating Agencies that included
39 updates and information exchange related to the alternatives.
40

41 Alternative D has been selected by the DOI as the preferred alternative in this DEIS, and
42 is supported by Western and the Basin States. DOI has also received positive feedback about this
43 alternative from other stakeholders in the AMWG. It was developed by the DOI based on the
44 results of the analysis of the other six alternatives. Alternative D adopted many of the best-
45 performing characteristics of Alternatives C and E. The effects of operations under these latter
46 two alternatives were first modeled, and the results of that modeling suggested ways in which

1 characteristics of each could be combined and modified to improve performance, reduce impacts,
2 and better meet the purpose, need, and objectives of the LTEMP. The impacts of Alternative D
3 were then evaluated using the same models used for other alternatives (Section 4.1), and these
4 results served as the basis for the assessments presented in Chapter 4. Subsequent to that
5 modeling, relatively minor modifications were made to Alternative D based on discussions with
6 Cooperating Agencies, and with the support of screening tool analyses.

7
8 To aid in the alternative development process, formal decision analysis tools were also
9 used for the LTEMP DEIS. Such tools are particularly useful for this application because the
10 LTEMP concerns the management of a very complex system with many—possibly competing—
11 resources of interest, and it involves uncertainty about the relationships between management
12 strategies and the responses of resources to those strategies. A structured decision analysis
13 process for LTEMP alternative development and evaluation was facilitated by
14 Dr. Michael Runge of the USGS to obtain multiple stakeholder viewpoints. This was
15 accomplished through a series of workshops and webinars involving LTEMP project managers;
16 DEIS analysts; technical representatives from FWS, BIA, Western, and AZGFD; and interested
17 AMWG stakeholders. See Section 1.7 for additional information on the role of decision analysis
18 in the LTEMP DEIS process, and Appendix C for a complete description of the structured
19 decision analysis process as applied to the LTEMP DEIS.

22 **2.2 DESCRIPTIONS OF ALTERNATIVES CONSIDERED IN DETAIL**

23
24 This section describes the seven alternatives considered for detailed analysis in the
25 LTEMP DEIS. Operations under all of these alternatives would use only existing dam
26 infrastructure. There are a number of experimental and management actions that would be
27 incorporated into all of the LTEMP alternatives, except where noted:

- 28
29 • High flow releases for sediment conservation. Implementation of high-flow
30 experiments (HFEs) under all alternatives are patterned after the current HFE
31 protocol (Reclamation 2011b), but each alternative includes specific
32 modifications related to the frequency of spring and fall HFEs, the triggers for
33 HFEs, and the overall process for implementation of HFEs, including
34 implementation considerations and conditions that would result in
35 discontinuing specific experiments.
- 36
37 • Nonnative fish control actions. Implementation of control actions for
38 nonnative brown and rainbow trout are patterned after those identified in the
39 Nonnative Fish Control Environmental Assessment (EA)
40 (Reclamation 2011a) and Finding of No Significant Impact
41 (Reclamation 2012b), but some alternatives include specific modifications
42 related to the area where control actions would occur, the specific actions to
43 be implemented, and the overall process for implementation of control
44 actions, including implementation considerations and conditions that would
45 result in discontinuing specific experiments. Nonnative fish control actions are
46 not included in Alternative F.

- 1 • Conservation measures established by the FWS for the proposed action.
2 Conservation measures identified in the 2011 Biological Opinion (BO) on
3 operations of Glen Canyon Dam (FWS 2011c) included the establishment of a
4 humpback chub refuge, evaluation of the suitability of habitat in the lower
5 Grand Canyon for the razorback sucker (*Xyrauchen texanus*), and
6 establishment of an augmentation program for the razorback sucker, if
7 appropriate. Other measures include humpback chub translocation; Bright
8 Angel Creek brown trout control; Kanab ambersnail (*Oxyloma haydeni*
9 *kanabensis*) monitoring; determination of the feasibility of flow options to
10 control trout including increasing daily down-ramp rates to strand or displace
11 age-0 trout, and high flow followed by low flow to strand or displace
12 age-0 trout; assessments of the effects of actions on humpback chub
13 populations; sediment research to determine effects of equalization flows; and
14 Asian tapeworm (*Bothriocephalus acheilognathi*) monitoring. Most of these
15 conservation measures are ongoing and are elements of existing management
16 practices (e.g., brown trout control, humpback chub translocation, and
17 sediment research to determine the effects of equalization flows), while others
18 are being considered for further action under the LTEMP (e.g., trout
19 management flows [TMFs]). New conservation measures or adjustments to
20 the existing ones may be developed for the preferred alternative.
21
- 22 • Experimental and management actions at specific sites such as nonnative plant
23 removal, revegetation with native species, and mitigation at specific and
24 appropriate cultural sites. Included are pilot experimental riparian vegetation
25 restoration actions planned by NPS. These actions would also have
26 involvement from Tribes to capture concerns regarding culturally significant
27 native plants, and would provide an opportunity to integrate Traditional
28 Ecological Knowledge in a more applied manner into the long-term program.
29
- 30 • Preservation of historic properties through a program of research, monitoring,
31 and mitigation to address erosion and preservation of archeological and
32 ethnographic sites and minimize loss of integrity at *National Register* historic
33 properties.
34
- 35 • Continued adaptive management under the Glen Canyon Dam Adaptive
36 Management Program, including a research and monitoring component as
37 more fully discussed in Section 1.6.
38

39 With operational flows limited to 45,000 cfs and below, the overall size of the riparian
40 area in Grand Canyon is expected to continue to decrease, primarily as a result of continuing lack
41 of water in the old high water zone and continued declines at the upper edges of the new high
42 water zone; however, the vegetation density within the riparian area is expected to continue to
43 increase. Exotic vegetation and monoculture species such as arrowweed are expected to continue
44 to increase and key native species (e.g., Goodding's willow) are expected to continue to
45 decrease.
46

1 Experimental riparian vegetation restoration activities would be implemented by NPS
2 under all alternatives except for Alternative A and would modify the cover and distribution of
3 riparian plant communities along the Colorado River. All activities would be consistent with
4 NPS Management Policies (NPS 2006d). NPS will work with Tribal partners and GCMRC to
5 experimentally implement and evaluate a number of vegetation control and restoration activities
6 on the riparian vegetation within the Colorado River Ecosystem in Grand Canyon National Park
7 (GCNP) and Grand Canyon National Resource Area (GCNRA). These activities would include
8 ongoing monitoring and removal of selected exotic plants, species in the corridor, systematic
9 removal of exotic vegetation at targeted sites, and full-scale restoration at targeted sites and
10 subreaches, which may include complete removal of tamarisk (both live and dead) and
11 revegetation with native vegetation. Treatments would fall into two broad categories, including
12 the control of exotic nonnative plant species and revegetation with native plant species. Principal
13 elements of this experimental riparian vegetation proposal include:

- 14
- 15 • Control exotic plant species that spread or are favored by dam operations,
16 focusing on tamarisk and other highly invasive species;
- 17
- 18 • Develop native plant materials for restoration uses through partnerships and
19 use of regional greenhouses;
- 20
- 21 • Restore native plant species to priority sites along the river corridor, including
22 native species of interest from Tribal perspectives;
- 23
- 24 • Control campsite vegetation encroachment at priority sites where camping
25 area has been lost;
- 26
- 27 • Manage vegetation to assist with cultural site protection.
- 28

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

38

39 In addition to these common elements, there are recent plans and decisions of the joint-
40 lead agencies and DOI-identified management actions that would be implemented under all
41 alternatives (e.g., NPS Comprehensive Fisheries Management Plan; NPS 2013e) or that could
42 influence implementation of alternatives and their component actions (e.g., Interim Guidelines
43 for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead;
44 Reclamation 2007a). These are described in Section 1.10. In general, these items, together with
45 existing laws and regulations (Section 1.9), establish "sideboards" that constrain the breadth and
46 nature of flow and non-flow actions that could be considered for inclusion in alternatives.

1 Under all alternatives, release patterns could be adjusted to provide ancillary services
2 including regulation and reserves for hydropower. Regulation is the minute-by-minute changes
3 in generation needed to maintain a constant voltage within a power control area. Regulation
4 affects instantaneous operations that deviate above and below the mean hourly flow without
5 affecting mean hourly flow. Spinning reserves in the control area served by the Colorado River
6 Storage Project are typically provided by power resources in the Aspinall Unit, a series of three
7 hydropower dams on the Gunnison River. However, under some relatively rare hydrological and
8 power resource conditions, Aspinall power resources cannot provide spinning reserves. When
9 this occurs the spinning reserve duty is typically placed on the Glen Canyon Dam powerplant. In
10 the event that these reserves are placed on Glen Canyon and at the same time need to be
11 deployed in response to a grid event, such as a system unit outage or downed power line,
12 Western would invoke exception criteria and within minutes or less increase the Glen Canyon
13 Dam power generation level up to the spinning reserve requirement. Associated turbine water
14 release rates would increase in tandem with higher power production.
15

16 Normal operations described under any alternative would be altered temporarily to
17 respond to emergencies. The North American Electric Reliability Corporation (NERC) has
18 established guidelines for the emergency operations of interconnected power systems. A number
19 of these guidelines apply to Glen Canyon Dam operations. These changes in operations would be
20 of short duration (usually less than 4 hr) and would be the result of emergencies within the
21 interconnected electrical system. Examples of system emergencies include insufficient
22 generating capacity; transmission system overload, voltage control, and frequency; system
23 restoration; and humanitarian situations (search and rescue).
24

25 The original notice of intent to prepare the LTEMP EIS identified the need to determine
26 whether to establish a recovery implementation program for endangered fish species below Glen
27 Canyon Dam. Although the GCDAMP has undertaken a number of actions that have previously
28 been identified as necessary for the recovery of humpback chub in FWS recovery planning
29 documents, the emphasis of that program is on mitigation and conservation actions specified in
30 the National Environmental Policy Act (NEPA) and the Endangered Species Act (ESA)
31 Section 7, Biological Opinions, for federal actions—not on the endangered fish species’ overall
32 needs to reach recovery. This limits the types of projects the GCDAMP can fund for the
33 endangered fish. A recovery implementation program could directly fund actions intended to
34 result in recovery. Recent findings of razorback sucker in western Grand Canyon and Lake
35 Mead, and evidence of recruitment in these areas, as well as in Lake Powell, highlight the need
36 for future recovery planning for this species in these geographic areas as well. FWS is currently
37 in the process of redrafting recovery plans for the four Colorado River “big river” species,
38 humpback chub, bonytail, Colorado pikeminnow, and razorback sucker. The LTEMP team finds
39 that, conceptually, a recovery implementation plan could be beneficial for these species.
40 However, the breadth of actions related to recovery may be outside the authority of the LTEMP
41 team. FWS could evaluate whether a recovery implementation program is appropriate in the
42 relevant areas of the Colorado River Ecosystem, or could choose to evaluate potential recovery
43 actions by developing recovery plans in coordination with partners.
44

1 Specific details of each of the LTEMP alternatives are described in Sections 2.3.1
2 to 2.3.8. Operational characteristics of LTEMP alternatives are presented in Table 2-1, and
3 condition-dependent and experimental elements are summarized in Table 2-2. In the descriptions
4 below, typical monthly flow patterns, including the mean, minimum, and maximum daily flows,
5 are presented for each alternative in years with an annual release volume of 8.23 maf. It is known
6 that a wide range of hydrologic conditions will occur over the LTEMP implementation
7 timeframe in response to intra-annual and inter-annual variability in basin-wide precipitation
8 cycles. Within a year, monthly operations are typically adjusted (increased or decreased) based
9 on numerous factors. For example, adjustments may be made because of changing annual runoff
10 forecasts, and, since 2007, application of the Interim Guidelines for Lower Basin Shortages and
11 Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a). To model each
12 LTEMP alternative, reservoir operation rules that represent how Glen Canyon Dam would be
13 operated under the alternative were developed for a range of hydrologic conditions and
14 equalization requirements.

15 16 17 **2.2.1 Alternative A (No Action Alternative)**

18
19 The Council on Environmental Quality (CEQ) requires inclusion of an “alternative of no
20 action” (Title 40, *Code of Federal Regulations*, Part 1502.14(d) [40 CFR 1502.14(d)]), which
21 serves as a baseline against which the impacts of “action” alternatives can be compared. For the
22 LTEMP DEIS, the No Action Alternative (referred to here as Alternative A) represents a
23 situation in which the DOI would not modify existing decisions related to operations.
24 Alternative A represents continued operation of Glen Canyon Dam as guided by the 1996 Record
25 of Decision (ROD) for operations of Glen Canyon Dam: Modified Low Fluctuating Flow
26 (MLFF), as modified by recent DOI decisions, including those specified in the 2007 ROD on
27 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for
28 Lakes Powell and Mead (until 2026) (Reclamation 2007b), the HFE EA (Reclamation 2011b),
29 and the Nonnative Fish Control EA (Reclamation 2011a) (both expiring in 2020). As is the case
30 for all alternatives, Alternative A also includes implementation of existing and planned NPS
31 management activities, with durations as specified in NPS management documents
32 (see Section 1.10).

33
34 Under Alternative A, daily flow fluctuations would continue to be determined according
35 to monthly volume brackets as follows: 5,000 cfs daily range for monthly volumes less than
36 600 kaf; 6,000 cfs daily range for monthly volumes between 600 kaf and 800 kaf; and 8,000 cfs
37 for monthly volumes greater than 800 kaf. Other operating criteria specified in the 1996 ROD are
38 identified in Table 2-1. Since 1996, operations under the 1996 ROD have typically resulted in
39 higher monthly water volume allocations in the high electrical demand months of December,
40 January, July, and August (Tables 2-1 and 2-3; Figure 2-1); operators have typically targeted
41 releases of slightly above 800 kaf in these high demand months in order to achieve the maximum
42 allowable daily fluctuation range (8,000 cfs). Figure 2-1 shows minimum, mean, and maximum
43 daily flows in an 8.23 maf year, assuming all days in a month adhere to the same mean daily
44 flow within a month. Figure 2-2 shows the hourly flows in a simulated 8.23-maf year within the
45 constraints of Alternative A. Figure 2-3 shows details of hourly flows during a week in July.

1 **TABLE 2-1 Operational Characteristics of LTEMP Alternatives**

Elements of Base Operations ^a	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Monthly pattern in release volume	Historic monthly release volumes. Higher volumes in high electric demand months of Dec., Jan., Jul., and Aug.	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	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	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

2-9

TABLE 2-1 (Cont.)

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

- ^a Base operations are defined as operations in those years when no condition-dependent or experimental actions are triggered. Examples of such actions include high-flow experiments, low summer flows, and TMFs (see Table 2-2).
- ^b Maximum flows presented are for normal operations, and may be exceeded as necessary for HFEs, emergency operations, and equalization purposes.
- ^c Values presented are the normal daily range in mean hourly flow for each alternative. Some variation in instantaneous flows within hours is allowed in all alternatives to accommodate emergency conditions, regulation requirements, and reserve requirements. For several alternatives, reduced fluctuations would be implemented after significant sediment inputs or after HFEs as described in Table 2-2.
- ^d Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

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

Condition-Dependent Elements	Trigger 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.–Mar.) 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 in same water year; no proactive spring HFE in first 2 years	No	No	Yes, if no other spring HFE in same water year

2-11

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger 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.–Oct.) 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	Follows existing protocol for entire LTEMP period	Follows existing protocol for entire LTEMP period	Follows existing protocol for entire LTEMP period	Follows existing protocol for 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 ^a) 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”) ^b	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 ($\pm 1,000$ cfs), in Feb. and Mar. (spring HFE) or Aug.–Oct. (fall HFE)	No	Yes ($\pm 1,000$ cfs), in Aug.–Oct. (fall HFE)	No change in operations, which already feature steady flows throughout the year	No change in operations, which already feature steady flows throughout the year

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Adjustments to Base Operations (Cont.)</i>								
Reduced fluctuations after HFES (“load-following curtailment”) ^b	Trigger: HFE Objective: Reduce erosion of newly built sandbars	No	No	Yes, until Dec. 1 after fall HFES, or May 1 after spring HFES	Yes ($\pm 1,000$ cfs), until the end of the month in which the fall HFE occurred	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 number of adult chub <7,000, <12°C at Little Colorado River confluence, and release temperature is sufficiently warm to achieve 14°C if low flows are provided; within-day range 2,000 cfs	Test in second 10 years if releases have been cold, number of adult chub $\geq 7,000$, and temperature of at least 16°C can be reached	No change in operations, which already feature low flows during summer	No
Sustained low flows for benthic invertebrate production	Trigger: None Objective: Increase invertebrate production especially mayflies, stoneflies, and caddisflies	No	No	No	Test, but avoid confounding effects on TMFs. Minimum monthly flow would be held constant on Saturdays and Sundays of May through Aug.	No	No	No

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Adjustments to Base Operations (Cont.)</i>								
Hydropower improvement flows (increased fluctuation levels)	Trigger: Annual volume ≤8.23 maf Objective: Test effect on sediment, HBC, 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
<i>Trout Management Actions</i>								
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	2 × 2 factorial design testing with/without HFE and with/without TMFs under warm and cold conditions	No	Test and implement if successful

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger 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								
Remove trout in Little Colorado River reach ^c	Trigger: High trout numbers in Little Colorado River reach, low humpback chub numbers Objective: Reduce competition and predation on chub	Yes	Yes	Yes	Yes	Yes	No	Yes
Riparian vegetation restoration	Trigger: None Objective: Improve vegetation conditions at key sites	No	Yes	Yes	Yes	Yes	Yes	Yes

- ^a 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 longer. Sediment concentration in the river would be monitored during the HFE at least during the first test.
- ^b 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.
- ^c 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).

1

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

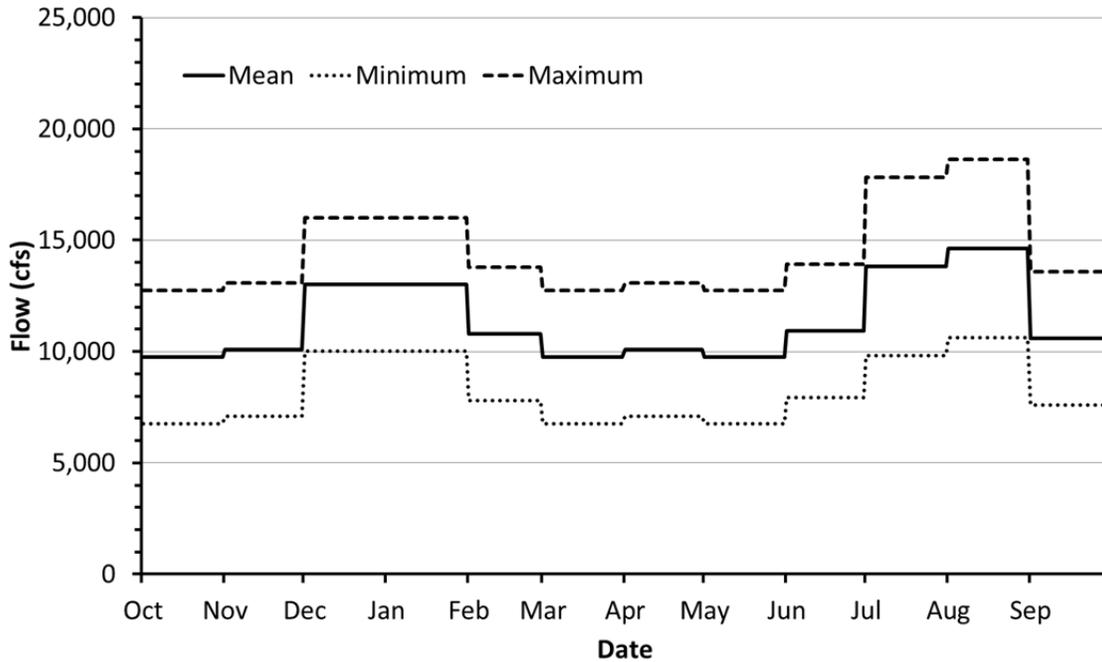
Month	Monthly Release Volume (kaf)	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	600	0.0729	9,758	6,000
November	600	0.0729	10,083	6,000
December	800	0.0972	13,011	8,000
January	800	0.0972	13,011	8,000
February	600	0.0729	10,804	6,000
March	600	0.0729	9,758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

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

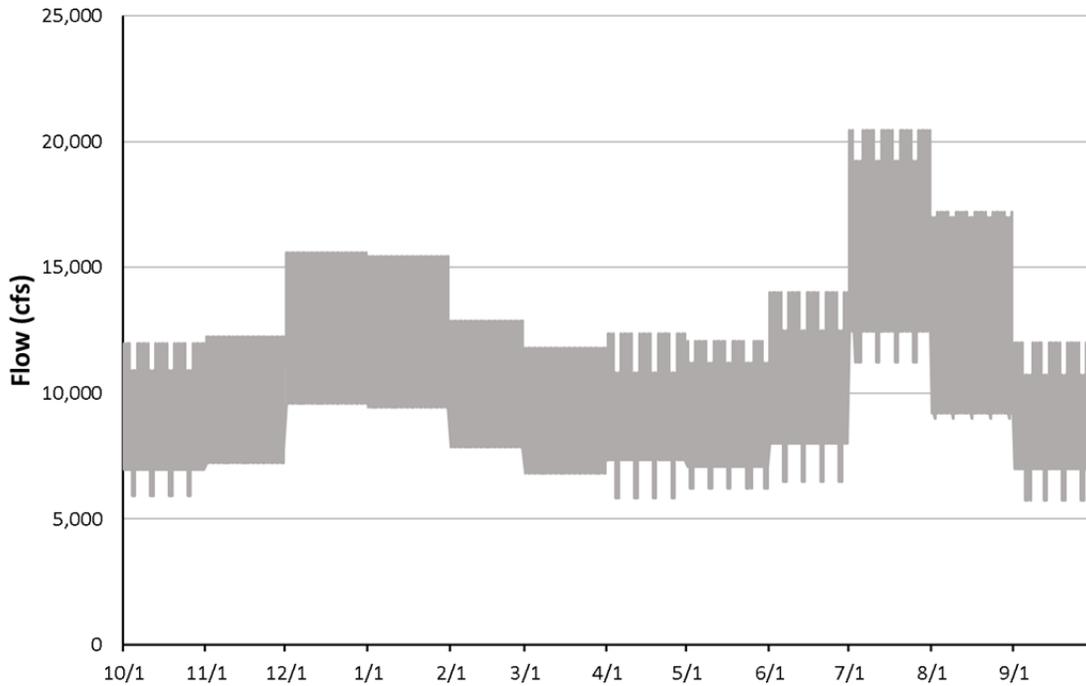
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Under the current HFE protocol (Reclamation 2011b), high-flow releases may be made in spring (March and April) or fall (October and November). HFE magnitude would range from 31,500 cfs to 45,000 cfs. The duration would range from less than 1 hr to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

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



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



6
 7 **FIGURE 2-2 Simulated Hourly Flows under Alternative A in an 8.23-maf Year**
 8 **(Note that there are differences in the mean, maximum, and minimum flows shown**
 9 **here and in Figure 2-1. These differences reflect flexibility in operational patterns**
 10 **allowed within the constraints of the alternative.)**

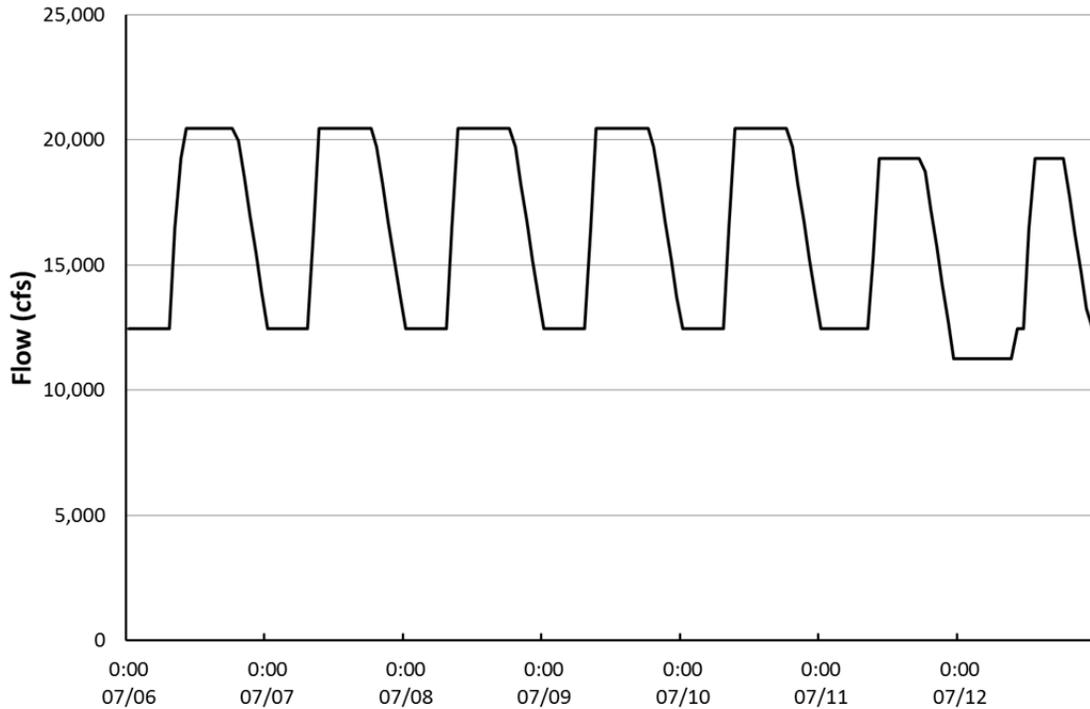


FIGURE 2-3 Simulated Hourly Flows under Alternative A for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

protocol after multiple (at least three) events have occurred. At the time the LTEMP DEIS was published, three HFEs had occurred using the HFE protocol; they took place on November 18–19, 2012 (24 hr at 42,300 cfs), November 11–16, 2013 (96 hr at 34,100 cfs), and November 10–15, 2014 (96 hr at 37,500 cfs).

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

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

1 would operate during the night over a period of up to 2 weeks, utilizing gas generators to power
2 lights and electrofishing equipment. Captured nonnative fish would be removed alive and
3 potentially stocked into areas that have an approved stocking plan, unless live removal fails, in
4 which case fish would be euthanized and used for later beneficial use (Reclamation 2011a).
5 Since 2011, the presence of whirling disease prohibits live removal of trout due to the risk of
6 spreading the disease to other waters.

7
8 Experimental components of Alternative A would be consistent with those that are part of
9 the current program, including those detailed in the HFE and Nonnative Fish Control EAs and
10 those identified as elements potentially common to all alternatives described above.

11 12 13 **2.2.2 Alternative B**

14
15 The objective of Alternative B is to increase hydropower generation while limiting
16 impacts on other resources and relying on flow and non-flow actions to the extent possible to
17 mitigate impacts of higher fluctuations. CREDA submitted this alternative for analysis and
18 consideration in the LTEMP DEIS. The alternative is similar to the “Option A Variation,” which
19 was one of four options developed and evaluated by the GCDAMP and GCMRC in early
20 planning efforts for the LTEMP DEIS. Alternative B focuses on non-flow actions and experiments
21 to address sediment resources, nonnative fish control, and native and nonnative fish
22 communities. Alternative B originally included several elements that were determined to be
23 either outside the scope of this DEIS, were already part of a previous NEPA process, or were
24 dismissed for other reasons. See Section 2.4 for elements that were considered but dismissed
25 (i.e., sediment augmentation, bubblers in the Lake Powell forebay, bypass tube generators, and
26 sediment check dams).

27
28 Under Alternative B, monthly volumes would be the same as under current operations,
29 but daily flow fluctuations would be higher than under current operations in most months
30 (Table 2-4; Figure 2-4). Increases would be greatest in February, which would have an
31 approximately 66% increase in fluctuations over current operations (10,000 cfs versus the
32 current 6,000 cfs range), while December and January would increase fluctuations approximately
33 50% (12,000 cfs versus the current 8,000 cfs range). Daily flow fluctuations would be increased
34 by approximately 25% in March, June, September, October, and November (8,000 versus
35 6,000 cfs), and in July and August (10,000 versus 8,000 cfs). Fluctuations would remain
36 unchanged relative to current operations (6,000 cfs) only in April and May (Tables 2-1, 2-2,
37 and 2-4; Figure 2-4). Compared to current operations, the hourly up-ramp rate would remain
38 unchanged at 4,000 cfs/hr, but the hourly down-ramp rate would be increased to 4,000 cfs/hr in
39 November through March and 3,000 cfs/hr in other months. Figure 2-4 shows minimum, mean,
40 and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same
41 mean daily flow within a month. Figure 2-5 shows the hourly flows in a simulated 8.23-maf year
42 within the constraints of Alternative B. Figure 2-6 shows details of hourly flows during a week
43 in July.

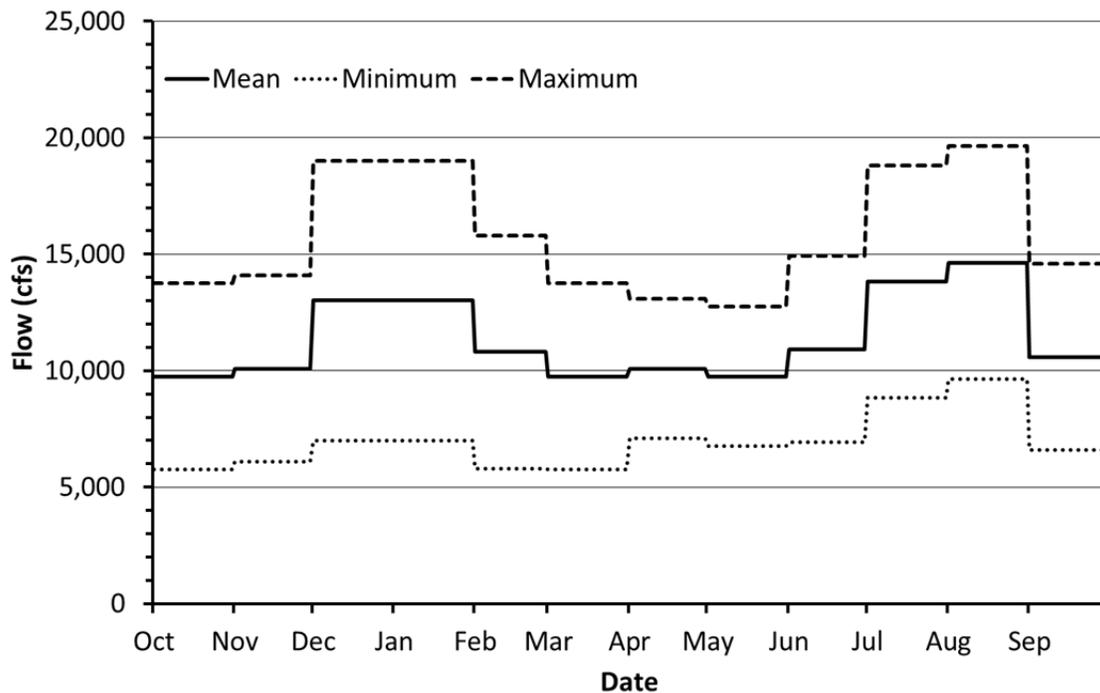
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TABLE 2-4 Flow Parameters under Alternative B in an 8.23-maf Year^a

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

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

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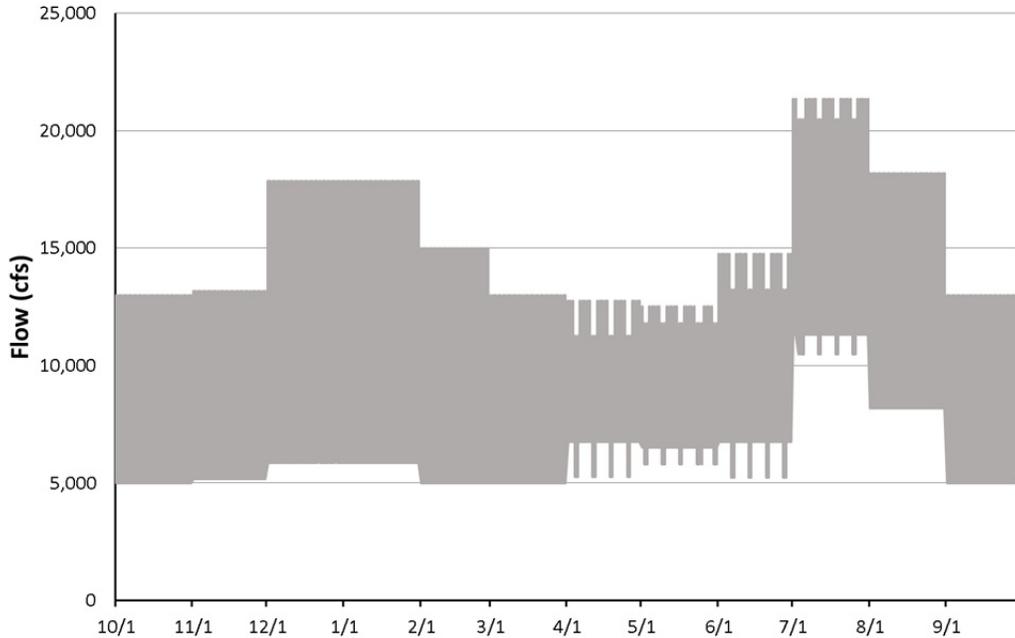


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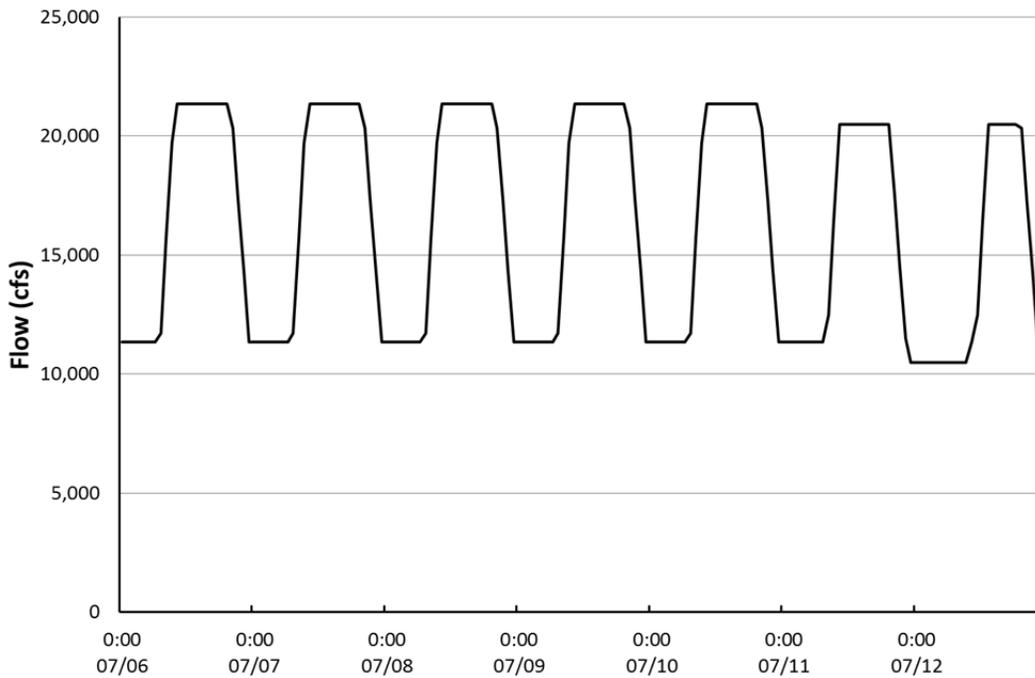
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FIGURE 2-4 Mean, Minimum, and Maximum Daily Flows under Alternative B in an 8.23-maf Year Based on Values Presented in Table 2-4



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



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

1 Alternative B includes these elements:
2

- 3 • Implementation of the Nonnative Fish Control protocol (Reclamation 2011a);
4
- 5 • Implementation of the HFE protocol (Reclamation 2011b), but limiting HFEs
6 to a maximum of one every other year;
7
- 8 • Experimental vegetation removal and restoration activities where appropriate.
9

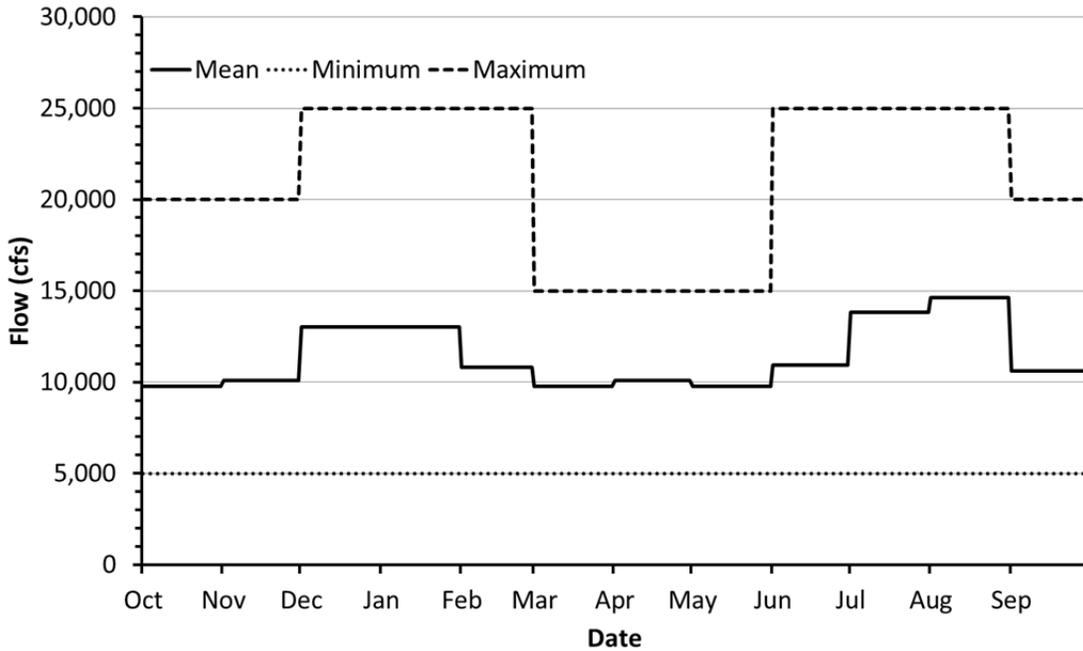
10 Experimental components of Alternative B would include those detailed in the HFE and
11 Nonnative Fish Control EAs (Reclamation 2011a,b). Alternative B also includes experiments to
12 analyze specific hypotheses. The specifics of the flows that would be tested in these experiments
13 would be subject to reservoir levels, hydrologic conditions, powerplant maintenance, and
14 economic considerations, and would include the following:
15

- 16 • **TMFs:** TMFs would maintain elevated flows for 2 or 3 days, followed by a
17 very sharp drop in flows to a minimum level for the purpose of reducing
18 annual recruitment of trout. TMFs are described in greater detail in
19 Section 2.2.3.
20
- 21 • **Hydropower improvement experiment:** Alternative B includes testing
22 maximum powerplant capacity releases in up to four years during the LTEMP
23 period, but only in years with annual volumes ≤ 8.23 maf. Under hydropower
24 improvement flows, within-day releases during the high-demand months of
25 December, January, February, June, July, and August would vary between
26 5,000 cfs at night and 25,000 cfs during the day; from September through
27 November within-day releases would vary from 5,000 to 20,000 cfs; and from
28 March through May within-day releases would vary from 5,000 to 15,000 cfs
29 (Figures 2-7, 2-8, and 2-9). Up- and down-ramp rates would be 5,000 cfs/hour
30 throughout the year. Years with annual flows ≤ 8.23 maf typically require
31 firming purchases by Western to meet contractual demand; thus, the
32 experiment could mitigate some of those more costly purchases in the high-
33 power months. The experiment is intended to evaluate the effects of maximum
34 powerplant operations on critical resources in the Colorado River Ecosystem.
35

36 Under Alternative B, experimental treatments would be implemented as soon as feasible
37 during the LTEMP period. Using this approach, experimental treatments would be implemented
38 at the initiation of the LTEMP period, and would be eliminated or retained based on their success
39 in providing resource benefits and avoiding adverse resource impacts.
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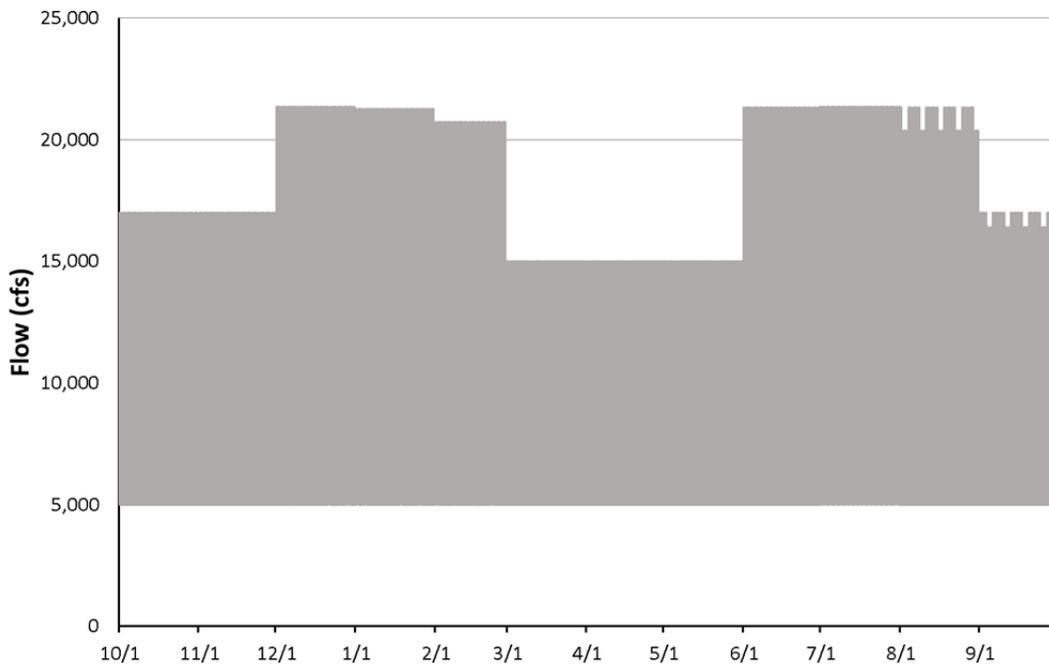
41 42 **2.2.3 Alternative C** 43

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



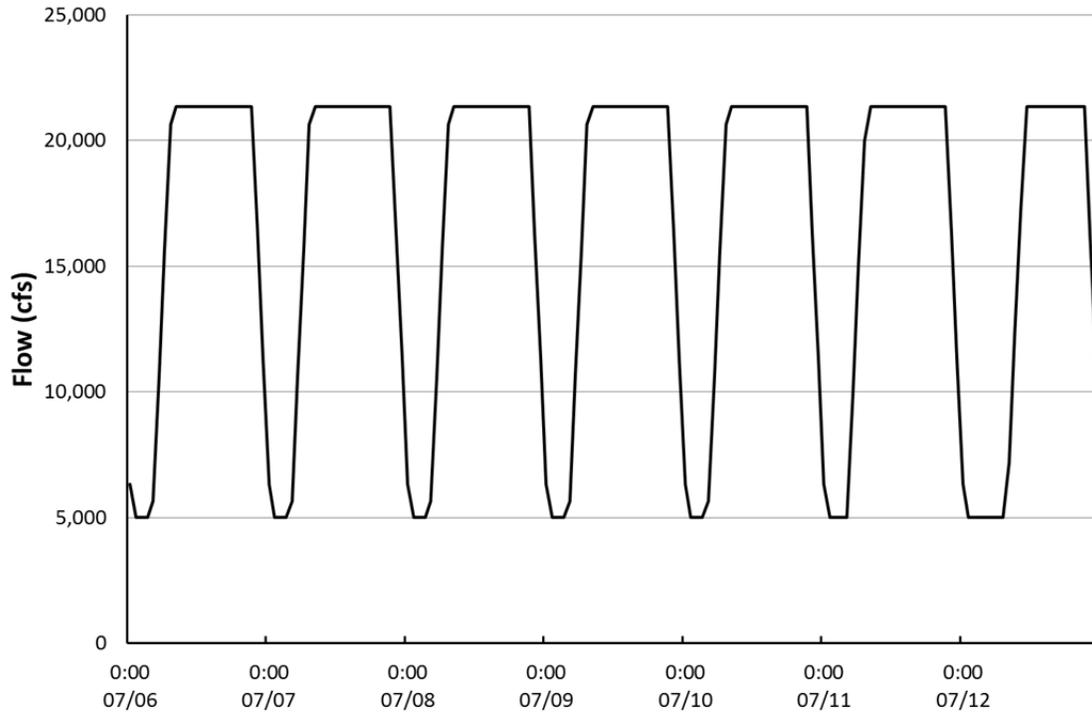
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FIGURE 2-7 Example Mean, Minimum, and Maximum Daily Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year



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



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

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2.2.3.1 Base Operations under Alternative C

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

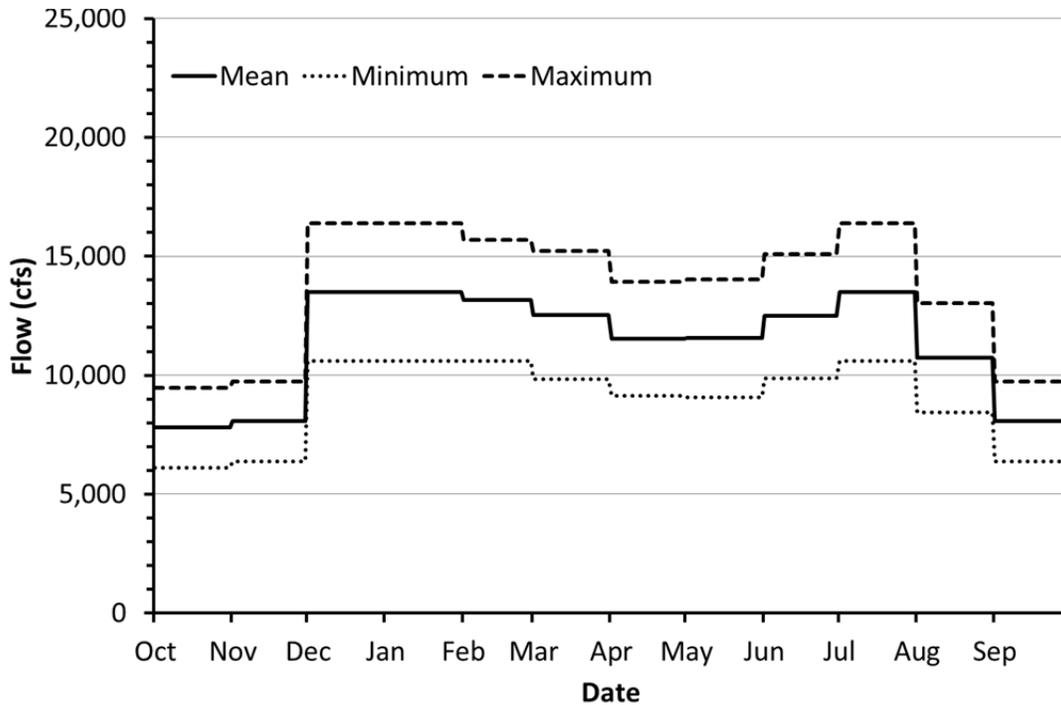
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TABLE 2-5 Flow Parameters under Alternative C in an 8.23-maf Year^a

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

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

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

1 Reductions in August and September volumes also were intended to result in a slight
2 increase in temperature relative to Alternative A at the confluence with the Little Colorado
3 River. Warmer temperatures are expected to provide humpback chub and other native fish with
4 some benefit during the critical time of year when many young-of-the-year fish move from the
5 Little Colorado River into the mainstem Colorado River.
6

7 Under base operations, the allowable within-day fluctuation range from Glen Canyon
8 Dam would be proportional to monthly volume (7× monthly volume in kaf; e.g., daily range in a
9 month with a volume of 800 kaf would be 5,600 cfs). The factor of 7 was chosen because it
10 would provide improvement in sediment conservation relative to MLFF while limiting the effect
11 on hydropower capacity and value. The down-ramp rate would be 2,500 cfs/hr (an increase from
12 1,500 cfs/hr under Alternative A); the up-ramp rate would be 4,000 cfs/hr as under
13 Alternative A. Figure 2-10 shows minimum, mean, and maximum daily flows in an 8.23-maf
14 year, assuming all days in a month adhere to the same mean daily flow within a month.
15 Figure 2-11 shows the hourly flows in a simulated 8.23-maf year within the constraints of
16 Alternative C. Figure 2-12 shows details of hourly flows during a week in July.
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19 **2.2.3.2 Experimental Framework for Alternative C**

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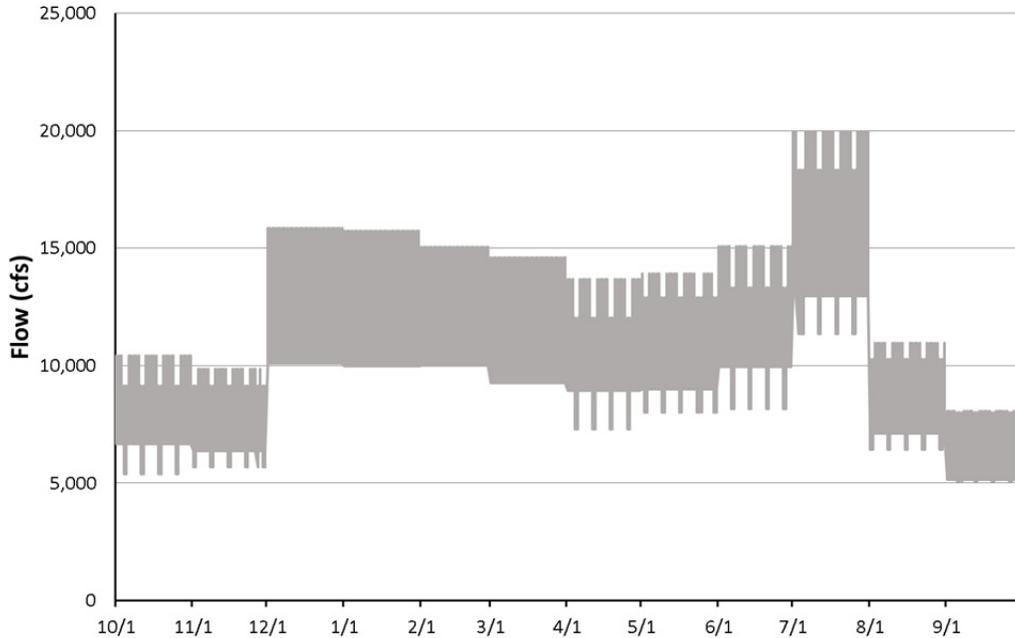
21 Alternative C adopts a condition-dependent experimental approach. The underlying
22 approach is to adopt a base operation that would serve as a long-term strategy to provide the
23 conditions needed to support natural and cultural resources while limiting impacts on
24 hydropower resources. Since there is uncertainty regarding future hydrologic conditions,
25 sediment supply, and resource response to operational, experimental, and environmental
26 conditions, Alternative C identifies condition-dependent flow and non-flow actions intended to
27 safeguard against unforeseen adverse changes in resource impacts, and to prevent irreversible
28 changes.
29
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31 **Overall Implementation Process for Experiments under Alternative C**

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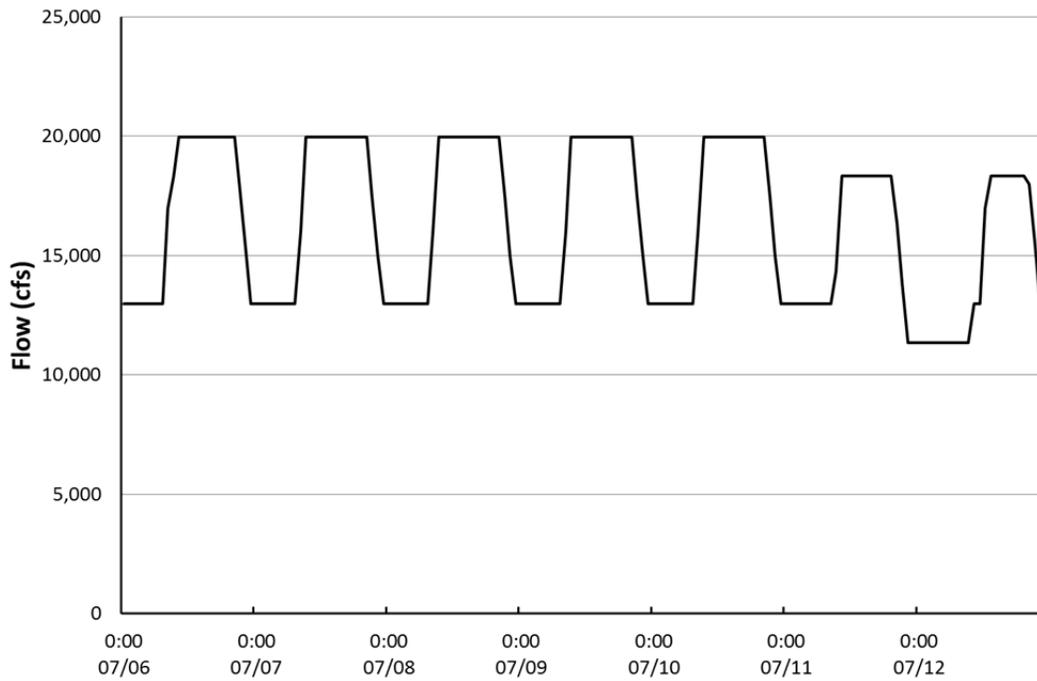
33 Alternative C would use decision trees, tied to information collected under a long-term
34 monitoring program, that would be implemented annually or, in some cases, as needed, to
35 determine operations and flow and non-flow actions in a given year. Implementation would be
36 closely integrated with existing operational and experimental decision processes involving
37 Reclamation, NPS, USGS, and GCDAMP. Decision trees for sediment-related and humpback
38 chub-related actions are shown in Figures 2-13 and 2-14.
39

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



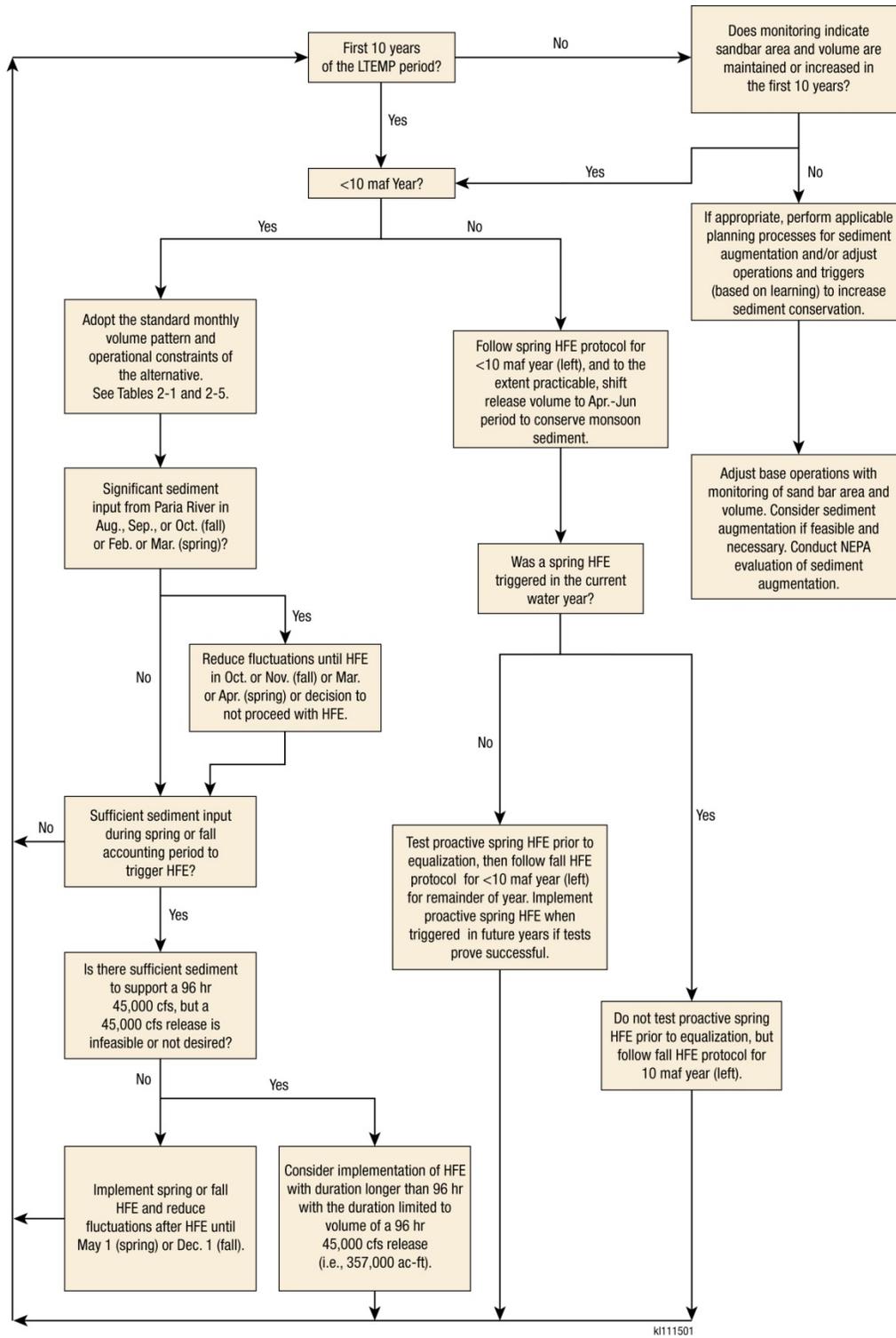
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FIGURE 2-11 Simulated Hourly Flows under Alternative C in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-10. These differences reflect flexibility in operational patterns allowed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



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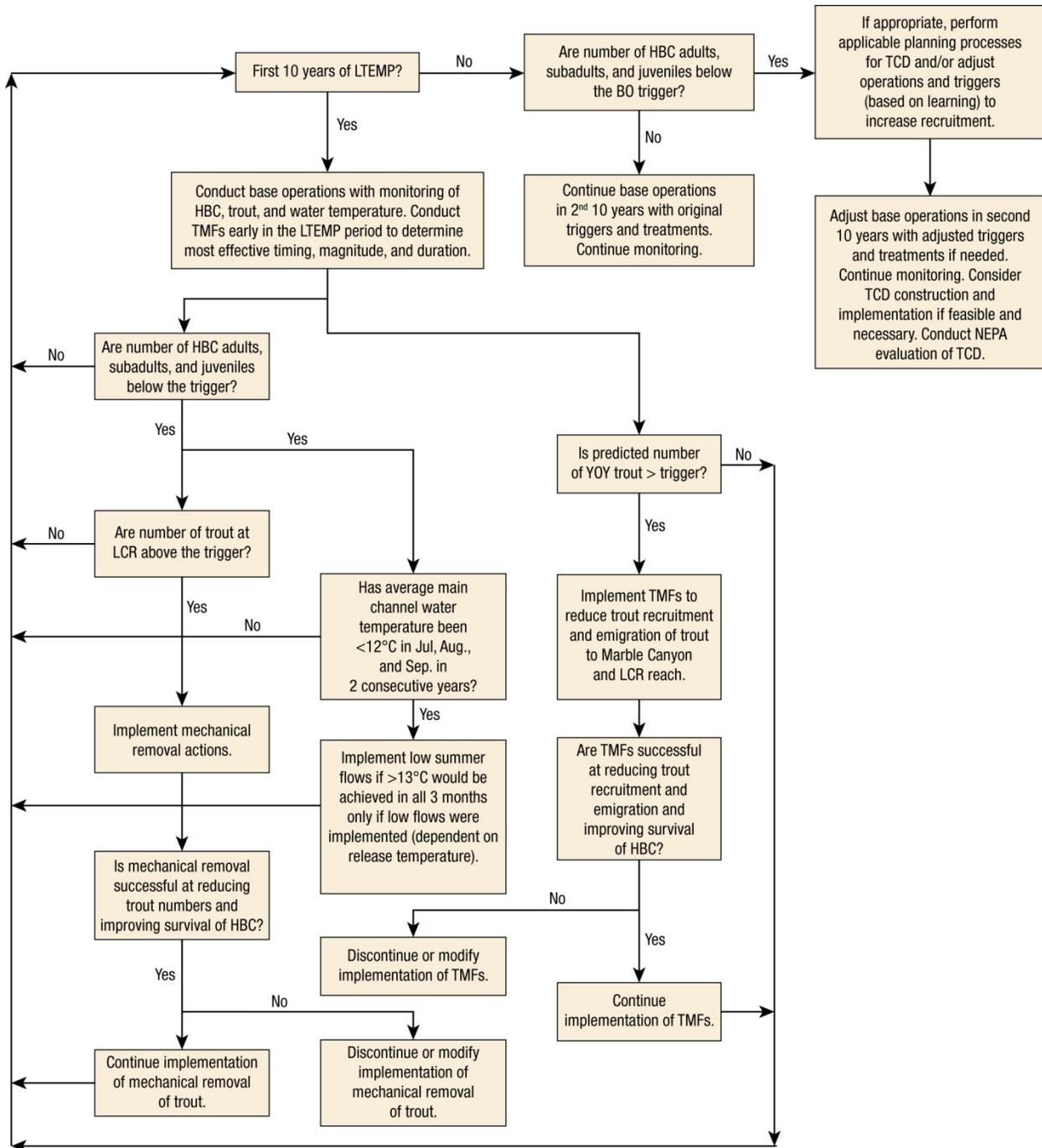
FIGURE 2-12 Simulated Hourly Flows under Alternative C for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)



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

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1
2 **FIGURE 2-13 Decision Tree for Sediment-Related Actions under Alternative C**
3 **(Implementation would be conditional on considerations presented in Table 2-6.**
4 **If off-ramp conditions listed in Table 2-6 exist, related experimental treatments**
5 **would be discontinued.)**



KI111502

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

1
2 **FIGURE 2-14 Decision Tree for Humpback Chub-Related Actions under Alternative C**
3 **(Implementation would be conditional on considerations presented in Table 2-6. If off-ramp**
4 **conditions listed in Table 2-6 exist, related experimental treatments would be discontinued.)**
5

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

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

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2

TABLE 2-6 (Cont.)

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

TABLE 2-6 (Cont.)

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

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations ^a	Long-Term Off-Ramp Conditions ^b	Action if Successful
<i>Aquatic Resource Experiments (Cont.)</i>						
Mechanical removal of rainbow trout in Little Colorado River reach	Trigger: Number of trout in Little Colorado River reach and number of humpback chub Objective: Test efficacy of control on trout numbers and competition and predation of chub	Implement in each year triggered unless determined ineffective, contingent on Tribal consultation	Up to six monthly removal trips (Feb.–Jul.)	Same as load-following curtailment	Little or no reduction in trout density at the Little Colorado River, or unacceptable adverse impacts on humpback chub population or other resources	Implement as adaptive treatment when triggered taking into consideration Tribal concerns
Low summer flows (minimum daily mean 5,000 to 8,000 cfs) to target $\geq 13^{\circ}\text{C}$ at Little Colorado River confluence	Trigger: Chub numbers are below trigger, water temperature has been $< 12^{\circ}\text{C}$ for two consecutive years and target temperature of $\geq 13^{\circ}\text{C}$ can only be achieved if drop to low flow Objective: Test efficacy of low summer flows on warming and humpback chub growth	If needed, two to three tests would be conducted in second 10 years of 20-year period; would not be implemented in first 10 years	3 months (Jul.–Sep.)	Same as load-following curtailment	No increase in growth and recruitment of humpback chub; increase in warmwater nonnative species or trout at the Little Colorado River; or adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when conditions allow
<i>Riparian Vegetation Experiment</i>						
Non-flow vegetation restoration activities	Trigger: None Objective: Improve vegetation conditions at key sites	Not applicable	20 years if successful pilot phase	Potential unacceptable site-specific impacts on key resources	Control and restoration techniques not effective or practical	Implement as adaptive treatment if invasive species can be reduced and native species increased

TABLE 2-6 (Cont.)

- a Annual determination by the DOI.
- b Temporary or permanent suspension if the DOI determines effects cannot be mitigated.
- 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.

1

1 In general, the first 10 years of base operations and strategic tests would be used to test
2 the effects of operations and experimental elements on resources, to determine the strategy for
3 the second 10 years of implementation, and, ultimately, to determine a long-term strategy for
4 Glen Canyon Dam operations and management actions that benefit important downstream
5 resources, while minimizing impacts on hydropower to the extent practicable.
6

7 If sandbar area and volume are maintained or increased in the first 10 years of the
8 LTEMP, the combination of base operations and HFE implementation would continue as
9 prescribed above. If sandbar area and volume declines during the first 10 years of LTEMP, the
10 HFE protocol and/or base operations may be modified to increase sediment conservation based
11 on information learned in the first 10 years. In addition, the DOI would consider applicable
12 planning processes for sediment augmentation and would conduct a separate NEPA evaluation of
13 augmentation if it is considered feasible and necessary to prevent continued loss of sediment
14 resources.
15

16 The relative effects of temperature and trout predation and/or competition on humpback
17 chub recovery are uncertainties that affect the selection of a future management strategy;
18 Alternative C would attempt to resolve this uncertainty. If after 10 years humpback chub are
19 declining, nonstructural options for creating warm water (i.e., flow manipulations) were not
20 successful in providing warmer temperatures, and evidence suggests that trout control alone is
21 not sufficient to improve humpback chub numbers, the DOI would consider a separate NEPA
22 evaluation and other appropriate planning processes for a structural change such as a temperature
23 control device (TCD). Research and monitoring during the first 10 years also could indicate that
24 other factors (e.g., parasites, pathogens, warmwater nonnatives, or food base) are limiting
25 humpback chub numbers. Such information would be used to develop additional condition-
26 dependent actions or adjustments to base operations other than those included in the alternative
27 at the start of the LTEMP.
28

29 No experimental flow actions are planned specifically for riparian vegetation under
30 Alternative C. However, as described in the introduction to Section 2.3, a pilot experimental
31 vegetation restoration program would be implemented under this and other alternatives to control
32 nonnative vegetation encroachment and restore native vegetation at selected sites. If successful,
33 vegetation restoration actions would be considered for inclusion as a regular non-flow action
34 implemented throughout the LTEMP period. There are no specific experimental tests or
35 condition-dependent actions that specifically focus on historic site preservation or Tribal cultural
36 properties and resources other than operations and actions intended to reduce sediment transport
37 in the active river channel. During the first 10 years of the LTEMP, continued evaluation of site
38 stability and integrity would be undertaken in coordination with sediment evaluations consistent
39 with the existing HFE protocol. Similarly, continued evaluation of Traditional Cultural
40 Properties and resources of cultural concern would be evaluated by traditional practitioners and
41 knowledgeable Tribal scholars. Mitigation would be undertaken to address resource impacts as
42 determined necessary in consultation with Tribes. If monitoring indicates that historical
43 properties preservation and Tribal cultural properties and resources are adversely affected by
44 operations in the first 10 years of LTEMP implementation, the DOI would consider modification
45 of operations to address aspects that, based on the results of monitoring and Tribal consultation,

1 are causing degradation of these resources, and would consider an increase in non-flow actions,
2 in consultation with the Tribes, to achieve these two resource goals.
3

4 Base operations under Alternative C would be experimentally modified in response to
5 changes in resource conditions or the need for equalization as specified under the 2007 Interim
6 Guidelines (Reclamation 2007a). The most important experiments relate to (1) implementation
7 of HFEs in response to sediment inputs or equalization flows; (2) reductions in flow fluctuation
8 in spring and fall in response to sediment inputs or the occurrence of HFEs; (3) flow actions in
9 the spring and summer to control the Glen Canyon reach trout population; and (4) reductions in
10 flows in certain years from July through September to provide warmer water for humpback chub
11 near the confluence with the Little Colorado River. Non-flow actions are largely limited to those
12 that are common to all alternatives as described at the beginning of Section 2.2.
13
14

15 **Sediment-Related Experiments To Be Evaluated under Alternative C**

16
17 Under Alternative C, spring and fall HFEs would be implemented when triggered during
18 the 20-year LTEMP period using the same Paria River sediment input thresholds as used under
19 the existing HFE protocol (Reclamation 2011b). HFE releases would be 1 to 96 hr long and
20 between 31,500 and 45,000 cfs. Depending on the cumulative amount of sediment input from the
21 Paria River during the spring (December through March) or fall (July through October)
22 accounting periods, the maximum possible magnitude and duration of HFE that would achieve a
23 positive sand mass balance in Marble Canyon, as determined by modeling, would be
24 implemented (see Section 2.2.1 for a brief description of the existing HFE protocol).
25

26 Daily fluctuations for load-following would be reduced (except for instantaneous
27 increases or decreases in flow to provide ancillary services)³ after significant sediment input
28 (sufficient input to trigger an HFE) from the Paria River in February or March (in anticipation of
29 a spring HFE); or August, September, or October (in anticipation of a fall HFE) to increase the
30 amount of sediment available for transport and deposition by spring and fall HFEs. These
31 reduced fluctuations would occur until an HFE was implemented or a decision to not implement
32 an HFE was made. If an HFE was implemented, the restriction in daily fluctuations would
33 continue after the HFE occurred until May 1 (spring HFE) or December 1 (fall HFE) to reduce
34 the erosion of newly formed sandbars. Under Alternative C, within-day fluctuations in hourly
35 flows would be reduced to a within-day range of 2,000 cfs (i.e., $\pm 1,000$ cfs of the mean daily
36 flow).
37

38 Sandbar monitoring after the 2011 equalization releases indicated that high rates of
39 sandbar erosion and sediment transport occurred during equalization. To offset these high
40 erosion and transport rates, Alternative C includes a proactive spring HFE in years when the
41 April forecast indicates an annual release ≥ 10 maf. In these years, a 24-hr spring high flow (up to

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

1 45,000 cfs) would be tested prior to the occurrence of high equalization releases to determine the
2 effectiveness of using high flows to conserve sediment downstream of the Paria River
3 confluence above the elevation of equalization flows. The high flow would be timed to occur
4 after the need for equalization has been determined, but before it was actually implemented. This
5 would likely result in proactive spring HFEs occurring in May or June.
6

7 Under Alternative C, a proactive spring HFE would not be tested if there had been a
8 spring HFE in the same water year. In high-volume years (≥ 10 maf) when there were no
9 proactive spring HFEs, higher monthly volumes would be shifted to the April through June time
10 period to the extent practicable to avoid sustained higher monthly flows and sediment transport
11 rates at the end of the year.
12

13 The existing HFE protocol allows for HFEs up to 96 hr long, but there will be some years
14 when a 45,000 cfs HFE is not feasible (e.g., one or more generating units are not available) and a
15 longer duration release would be possible and desirable to achieve sediment goals. Under
16 Alternative C, longer duration HFEs that did not exceed the total volume of a 96-hr, 45,000-cfs
17 HFE (i.e., 357,000 ac-ft) would be allowed.
18
19

20 **Aquatic Resource-Related Experiments To Be Evaluated under Alternative C**

21

22 Under Alternative C, experimental flow and non-flow actions would be triggered by
23 estimated numbers of rainbow trout, a combination of estimated numbers of rainbow trout and
24 humpback chub, or measured water release temperature at Glen Canyon Dam, depending on the
25 action under consideration. Humpback chub triggers and trout triggers would be developed in
26 consultation with the FWS and AZGFD. These triggers may be modified based on
27 experimentation conducted early in the LTEMP period.
28

29 The humpback chub population in Grand Canyon has increased considerably under
30 MLFF operations since the early 2000s. During this period, relatively warmer temperatures
31 began to be reached at the Little Colorado River confluence as a consequence of lower reservoir
32 elevations and concomitantly higher release temperatures (see Section 3.5.3); this warming may
33 have contributed to the increase in humpback chub recruitment. Base operations under
34 Alternative C are intended to support continued and possibly improved humpback chub
35 recruitment. Ongoing monitoring would be used to determine the need to adjust base operations
36 to benefit humpback chub.
37

38 Under Alternative C, water temperature and trout numbers would be considered when
39 determining the actions to take when chub numbers drop below the trigger levels identified
40 above. Triggers for temperature and trout numbers would be used under Alternative C to trigger
41 two potential actions: (1) low summer flows and (2) mechanical removal of trout. These are
42 discussed individually below.
43

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

7 ***Mechanical Removal of Trout under Alternative C***

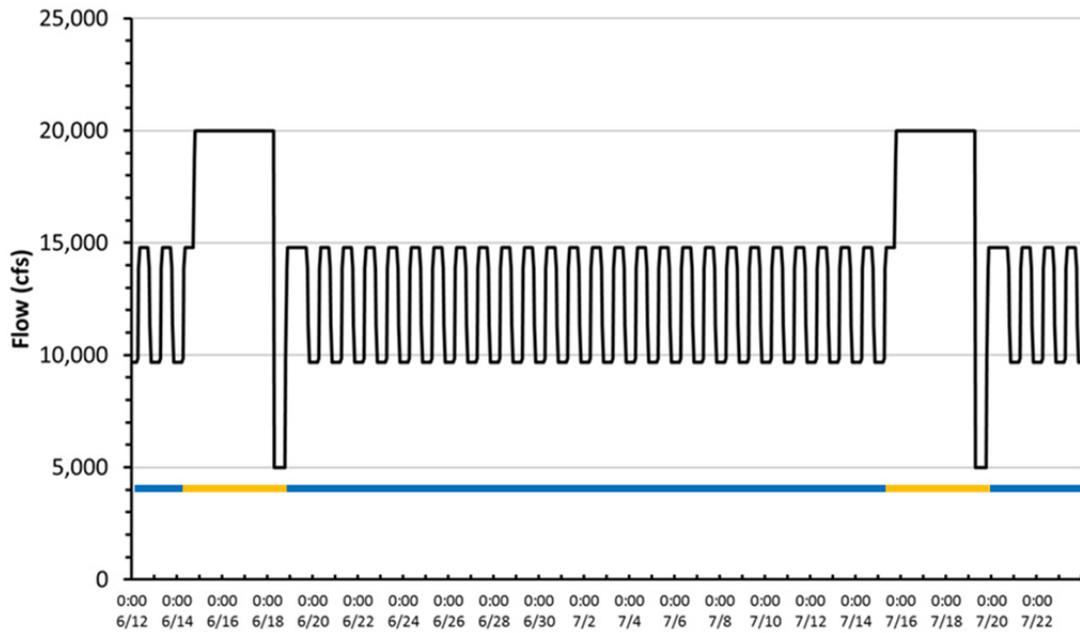
8
9 Mechanical removal would occur at the Little Colorado River confluence (rainbow and
10 brown trout), and would follow the protocol evaluated in the Nonnative Fish Control EA
11 (Reclamation 2011a; see Section 2.2.1 of this DEIS for a brief description of the protocol).
12 Mechanical removal in the Little Colorado River reach (RM 56–66) would be triggered by low
13 humpback chub and high trout abundance estimates in the Little Colorado River reach.
14 Mechanical removal, however, may be initiated in response to ongoing management of the trout
15 fishery by the NPS (an element common to all alternatives) or in response to declining
16 humpback chub numbers. The DOI recognizes that lethal mechanical removal is a concern for
17 Tribes, particularly the Pueblo of Zuni, because it is a taking of life in the canyon. To the extent
18 practicable, removal practices would include finding beneficial uses for removed fish, as has
19 been practiced for trout removal actions at Bright Angel Creek.

22 ***Trout Management Flows under Alternative C***

23
24 TMFs are a special type of fluctuating flow designed to reduce the recruitment of trout by
25 disadvantaging young-of-the-year (YOY) trout (Figure 2-15). TMFs have been proposed and
26 developed on the basis of research described in Korman et al. (2005). The underlying premise of
27 TMFs is based on observations that YOY trout tend to occupy near-shore shallow-water habitats
28 to avoid predation by larger fish. TMFs feature repeated fluctuation cycles that consist of
29 relatively high flows (e.g., 20,000 cfs) sustained for a period of time (potentially ranging from
30 2 days to 1 week) followed by a rapid drop to a very low flow (e.g., 5,000 to 8,000 cfs).⁴ This
31 low flow would be maintained for a period of less than a day (e.g., 12 hr) to prevent adverse
32 effects on the food base. Low flows would be timed to start in the morning, after sunrise, to
33 expose stranded fish to direct sunlight and heat. Up-ramp rates to the TMF would be the same as
34 the limit for this alternative overall (i.e., 4,000 cfs/hr). The down-ramp from peak to base would
35 be over a single hour (e.g., 15,000 cfs/hr for a drop from 20,000 cfs to 5,000 cfs). In a TMF flow
36 cycle, YOY trout are expected to occupy near-shore habitat when flows are highest, and would
37 be stranded by the sudden drop to low flow. Because older age classes of trout tend to occupy
38 deeper habitats toward the middle of the river channel, they are less susceptible to stranding and
39 are less likely to be directly affected by

40

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



1
 2 **FIGURE 2-15 Example Implementation of a Two-Cycle TMF in June and July with**
 3 **Resumption of Normal Fluctuations between Cycles and Afterward (Monitoring for**
 4 **effectiveness would occur before and after each cycle. The horizontal line below the**
 5 **graph shows periods of normal fluctuation [blue] and TMFs [orange].)**
 6

7
 8 TMFs. TMFs would be used to control trout recruitment in the Glen Canyon reach to manage the
 9 rainbow trout fishery, and to limit emigration of juvenile trout to downstream reaches,
 10 particularly to habitat occupied by humpback chub near the confluence with the Little Colorado
 11 River. Triggers for implementation of TMFs would be determined in consultation with the
 12 AZGFD.
 13

14 It should be noted that several Tribes have expressed concerns about TMFs as a taking of
 15 life within the canyon without a beneficial use. The Pueblo of Zuni has expressed concern that
 16 the taking of life by trout stranding has an adverse effect on the Zuni value system. The joint-
 17 lead agencies will continue to work with the Tribes regarding options for trout management.
 18

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

1 increased based on experimental testing to as many as three cycles per month for 3 months (May,
2 June, and July).

3 4 5 ***Low Summer Flows under Alternative C*** 6

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

15
16 The ability to achieve target temperatures at the Little Colorado River confluence by
17 providing lower flows is dependent on release temperatures, which are in turn dependent on
18 reservoir elevation. For example, using the temperature model of Wright, Anderson et al. (2008),
19 in an 8.23-maf year, release temperatures of 9.6°C, 9.8°C, and 10.5°C would be needed in July,
20 August, and September, respectively, to achieve a target temperature of 13°C at the Little
21 Colorado River confluence at flows of 8,000 cfs.

22
23 Release temperatures fall into three categories for any temperature target: (1) too low to
24 warm to target temperature even at low flow; (2) high enough to warm to target temperature only
25 if low flows (5,000 to 8,000 cfs) are provided; and (3) high enough to achieve target temperature
26 regardless of the flow level. Low flows would only be triggered in years that fell into the second
27 category. This is a fairly rare situation; modeling of 63 20-year periods determined that low
28 summer flows would be triggered in at most four years per 20-year period.

29
30 A decision as to whether low summer flows would be provided in a given year would be
31 made by May 1. Such a decision would be based on reservoir and temperature modeling, and
32 other resource conditions in addition to annual water delivery requirements. Because fluctuations
33 have relatively little effect on mainstem water temperature and humpback chub, minor within-
34 day flow fluctuations (i.e., ±1,000 cfs) would be allowed. If triggered, low summer flows would
35 be provided in at least 2 years (not necessarily consecutive), and the response of chub would be
36 determined.

37
38

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

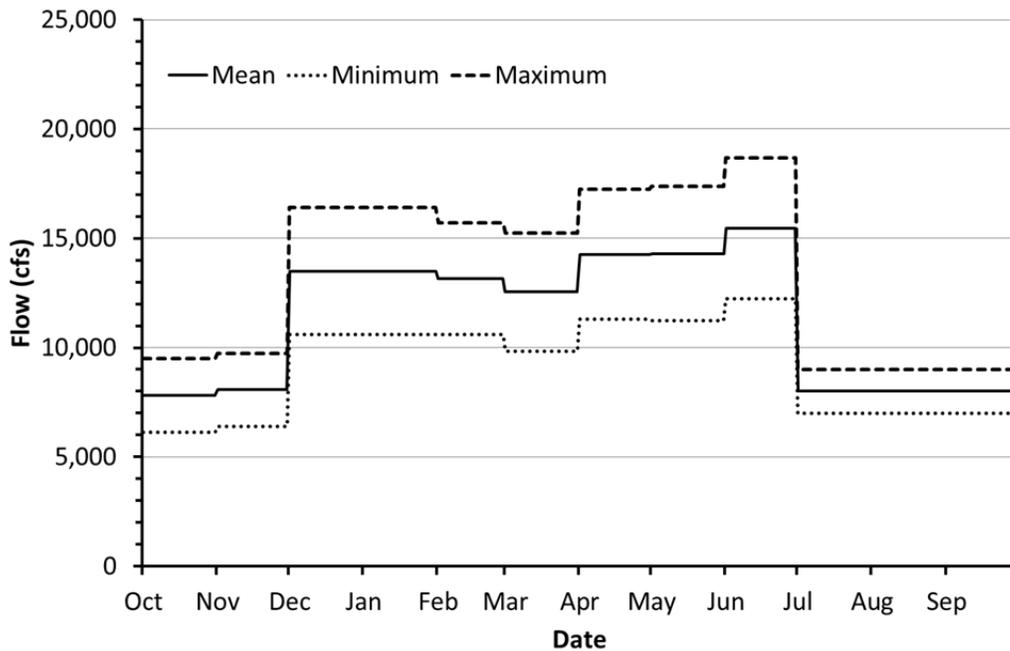
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TABLE 2-7 Flow Parameters for a Year with Low Summer Flows under Alternative C in an 8.23-maf Year^a

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

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

3
4



5
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8

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

1 **2.2.4 Alternative D (Preferred Alternative)**
2

3 The objective of Alternative D (the preferred alternative) is to adaptively operate Glen
4 Canyon Dam to best meet the resource goals of the LTEMP (Section 1.4). Like Alternative C,
5 Alternative D features condition-dependent flow and non-flow actions that would be triggered by
6 resource conditions.
7

8 Alternative D was developed by the DOI after a full analysis of the other six LTEMP
9 alternatives had been completed. This alternative was chosen as the preferred alternative by the
10 DOI, and its selection as the preferred alternative was supported by Western Area Power
11 Administration and the Basin States. Alternative D adopts operational and experimental
12 characteristics from Alternative C and Alternative E. The effects of operations under
13 Alternatives C and E were modeled, and the results of that modeling suggested ways in which
14 characteristics of each could be combined and modified to improve performance and reduce
15 impacts, while meeting the purpose, need, and objectives of the LTEMP DEIS.
16

17 On the basis of modeling results for Alternative C and E, discussions with subject matter
18 experts and Cooperating Agencies, and specific impact analyses of various potential
19 Alternative D characteristics conducted using the screening tool (see Section 2.1 for a discussion
20 of the models integrated in the screening tool), the DOI developed the operational and
21 experimental characteristics of Alternative D. This formulation of the alternative then was
22 modeled with the same models used for the analysis of the original six alternatives. After this
23 modeling of Alternative D was completed, several adjustments were made to specific operational
24 and experimental characteristics based on discussions with Cooperating Agencies and
25 stakeholders. These adjustments included (1) a change in August volume in an 8.23-maf year
26 from 750 to 800 kaf; (2) elimination of load-following curtailment prior to sediment-triggered
27 HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE; and
28 (4) a ban on sediment-triggered spring HFEs in the same water year as an extended-duration fall
29 HFE. The description of Alternative D provided in this section represents the final version of the
30 alternative that resulted from these changes.
31

32 Operational characteristics of Alternative D are presented in Table 2-1, and condition-
33 dependent experimental elements are summarized in Table 2-2. The alternative uses decision
34 trees to identify when a change in base operations or some other planned action is needed to
35 protect resources. Experimental flows and non-flow actions could be triggered by changes in
36 sediment input, humpback chub numbers and population structure, trout numbers, and water
37 temperature. Alternative D differs from Alternatives C and E in the specific trigger conditions
38 and actions that would be taken.
39

40
41 **2.2.4.1 Base Operations under Alternative D**
42

43 Under Alternative D, monthly water volumes would be comparable to those of
44 Alternative E, except that August and September volumes would be higher. Under Alternative D,
45 the total monthly release volume of October, November, and December would be equal to that
46 under Alternative A to avoid the possibility of the operational tier differing from that of

1 Alternative A, as established in the Interim Guidelines (Reclamation 2007a). The August volume
2 was set to a moderate volume level (800 kaf in an 8.23-maf release year) to balance sediment
3 conservation prior to a potential HFE and power-production and capacity concerns. January
4 through July monthly volumes were set at levels that roughly track Western's contract rate of
5 delivery (CROD). This produced a redistribution of monthly release volumes under
6 Alternative D that would result in the most even distribution of flows of any alternative except
7 for Alternative G.
8

9 Under base operations of Alternative D, the allowable within-day fluctuation range from
10 Glen Canyon Dam would be proportional to the volume of water scheduled to be released during
11 the month ($10 \times$ monthly volume in kaf in the high-demand months of June, July, and August
12 and $9 \times$ monthly volume in kaf in other months; Table 2-8; Figure 2-17). For example, the daily
13 fluctuation range in July with a scheduled release volume of 800 kaf would be 8,000 cfs, and the
14 daily fluctuation range in December with the same scheduled release volume would be 7,200 cfs.
15 The maximum allowable daily fluctuation range in flows in any month would be 8,000 cfs,
16 which is also the maximum daily fluctuation range under Alternative A. The down-ramp rate
17 under Alternative D would be limited to no greater than 2,500 cfs/hr, which is 1,000 cfs/hr
18 greater than what is allowed under Alternative A. The up-ramp rate would be 4,000 cfs/hr, and
19 this is the same as what is allowed under Alternative A. Figure 2-17 shows minimum, mean, and
20 maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same
21 mean daily flow within a month. Figure 2-18 shows the hourly flows in a simulated 8.23-maf
22 year within the constraints of Alternative D. Figure 2-19 shows details of hourly flows during a
23 week in July.
24

25 Annually, Reclamation will develop a hydrograph based on the characteristics above.
26 Reclamation will seek consensus on the annual hydrograph through monthly operational
27 coordination calls with governmental entities, and regular meetings of the GCDAMP Technical
28 Working Group (TWG) and AMWG. Reclamation will conduct monthly Glen Canyon Dam
29 operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, and BIA),
30 Western, and representatives from the Basin States and Upper Colorado River Commission
31 (UCRC). The purpose of these meetings or calls is for the participants to share and seek
32 information on Glen Canyon Dam operations. One liaison from each Basin State and from the
33 UCRC may participate in the monthly operational coordination meetings or calls.
34
35

36 **2.2.4.2 Operational Flexibility under Alternative D**

37

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

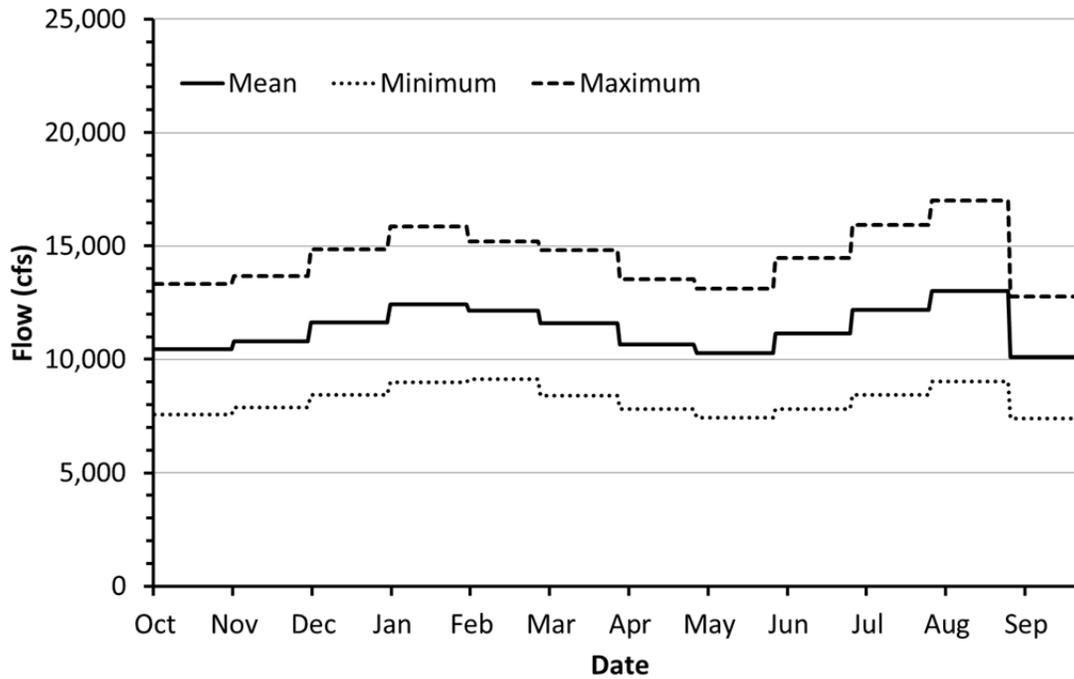
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TABLE 2-8 Flow Parameters under Alternative D in an 8.23-maf Year^a

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

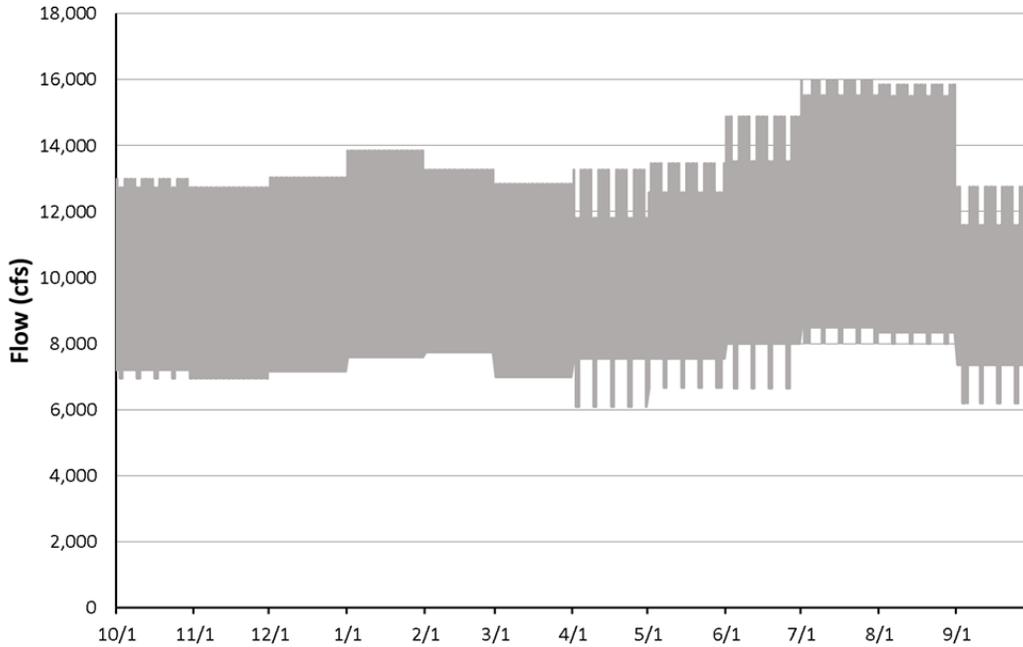
^a Within a year, monthly operations may be increased or decreased based on factors referenced in Section 2.2.4.2.

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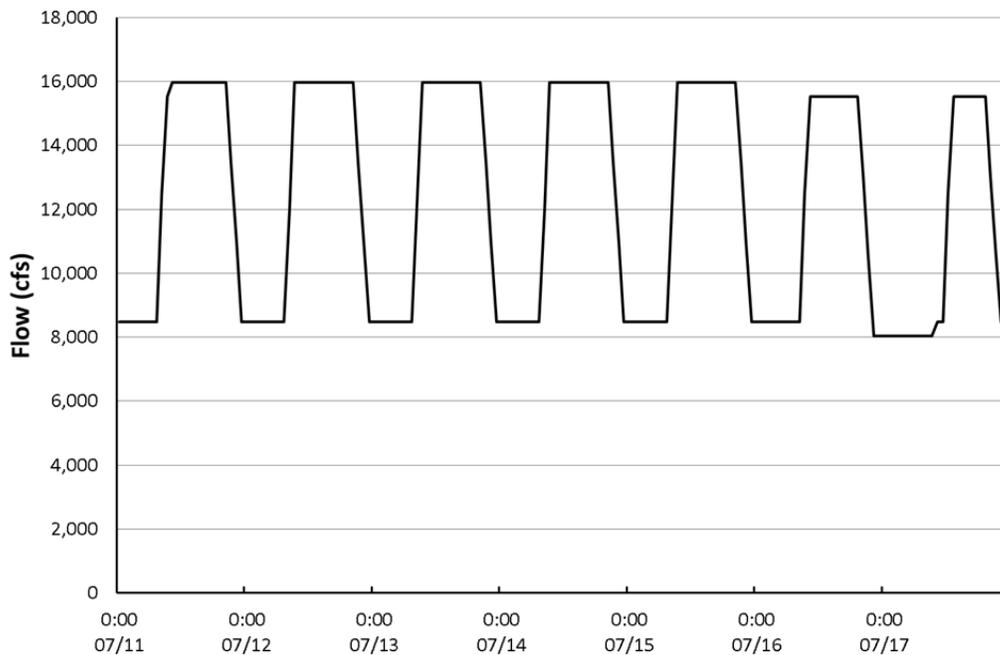
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FIGURE 2-17 Mean, Minimum, and Maximum Daily Flows under Alternative D in an 8.23-maf Year Based on Values Presented in Table 2-8



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



8
9
10
11

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

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

- 5
- 6 • For water distribution purposes, volumes may be adjusted to allocate water
7 between the Upper and Lower Basins consistent with the Law of the River as
8 a result of changing hydrology;
- 9
- 10 • For resource-related issues that may occur uniquely in a given year, release
11 adjustments may be made to accommodate nonnative species removal, to
12 assist with aerial photography, or to accommodate other resource
13 considerations separate from experimental treatments under the LTEMP;
- 14
- 15 • For hydropower-related issues, adjustments may occur to address issues such
16 as electrical grid reliability, actual or forecasted prices for purchased power,
17 transmission outages, and experimental releases from other Colorado River
18 Storage Project dams.
- 19

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

28

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

31

32

33 **2.2.4.3 Experimental Framework for Alternative D**

34

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

40

41

42 **Overall Implementation Process for Experiments under Alternative D**

43

44 Prior to implementation of any experiment, the relative effects of the experiment on the
45 following resource areas will be evaluated and considered: (1) water quality and water delivery,
46 (2) humpback chub, (3) sediment, (4) riparian ecosystems, (5) historic properties and traditional

1 cultural properties, (6) Tribal concerns, (7) hydropower production and the Basin Fund, (8) the
2 rainbow trout fishery, (9) recreation, and (10) other resources. Although nine key resources are
3 listed for consideration on a regular basis, DOI intends to retain sufficient flexibility in
4 implementation of experiments to allow for response to unforeseen circumstances or events that
5 involve any other resources not listed here. The recent discovery of nonnative green sunfish in
6 the Glen Canyon reach illustrates the need to be responsive to unforeseen conditions.

7
8 The proposed approach differs fundamentally from a more formal experimental design
9 (e.g., before-after control-impact design, factorial design) that attempts to resolve uncertainties
10 by controlling for or treating potentially influential or confounding factors. There are several
11 reasons to avoid such a formal design and instead focus on the condition-dependent approach
12 described here. Among these are (1) the difficulties in controlling for specific conditions in a
13 system as complex as the Colorado River; (2) wide variability in temperature and flow
14 conditions that are important drivers in ecological processes; (3) inherent risk of some
15 experimentation to protected sensitive resources, in particular, endangered humpback chub;
16 (4) conflicting multiple-use values and objectives; and (5) low expected value-of-information for
17 the uncertainties that could be articulated, and around which a formal experimental design would
18 be established. For these reasons, a condition-dependent adaptive approach is proposed.

19
20 The alternative works off the principle that a condition-dependent adaptive design is
21 preferable to a formal experimental design because of the need for a flexible and adaptive
22 program that is responsive to learning. A more formal experimental design, while potentially
23 beneficial in resolving specific uncertainties, would involve multiple-year tests under different
24 conditions, and with sufficient replicates of experimental conditions to statistically test the
25 significance of treatment effects. Such an experimental design would necessarily span a period of
26 years, during which environmental conditions would undoubtedly vary, and thus confound
27 interpretation of results. The duration of the experiment could be lengthened and the potential for
28 confounding effects increased if there was a desire to test system response under specific
29 conditions that cannot be controlled (e.g., annual volume, water temperature, sediment load,
30 species population levels). These factors make a formal experimental design impractical in the
31 Grand Canyon. Like Alternatives C and E, Alternative D would use condition-dependent triggers
32 to inform operations and experimental flow and non-flow treatments in a given year.

33
34 Implementation criteria for condition-dependent experimental treatments of Alternative D
35 are provided in Table 2-9, and decision trees for implementation of experimental treatments are
36 presented in Figures 2-20 and 2-21. (Note: In both of these figures, triggering would also be
37 conditional on annual implementation considerations and long-term off-ramps presented in
38 Table 2-9. The nodes shown in rectangles are condition-dependent action nodes; the nodes
39 shown in circles are information-dependent nodes that require the evaluation of accumulated
40 evidence.) Included in Table 2-9 are the triggers for experimental changes in operations,
41 implementation considerations for determining if an experimental treatment should proceed,
42 conditions that would cause the treatment to be terminated prior to completion (i.e., off-ramps),
43 and the number of replicates that are initially considered needed. In many cases, two to three
44 replicates of an experimental treatment are considered necessary. The results of these tests would
45 be used to determine if these condition-dependent treatments should be retained as part of the
46 suite of long-term actions implemented under LTEMP. In other cases, following the process

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

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations ^a	Long Term Off-Ramp Conditions ^b	Action if Successful
<i>Sediment Treatments</i>						
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Mar.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Not conducted during first 2 years of LTEMP, otherwise implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources; unacceptable cumulative effects of sequential HFEs; spring HFEs will not occur in the same water year as an extended-duration HFE (>96 hr)	HFEs were not effective in building sandbars; or unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when triggered and existing resource conditions allow
Proactive spring HFE up to 45,000 cfs (Apr., May, or Jun.)	Trigger: High-volume year with planned equalization releases (≥10 maf) Objective: Protect sand supply from equalization releases	Not conducted during first 2 years of LTEMP, otherwise implement in each year triggered, dependent on resource condition and response	First test 24 hr; subsequent tests could be shorter, but not longer, depending on results of first tests	Same as spring HFEs	Same as spring HFEs	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations	Long Term Off-Ramp Conditions	Action if Successful
<i>Sediment Treatments (Cont.)</i>						
Fall HFE up to 45,000 cfs in Oct. or Nov.	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Oct.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources; unacceptable cumulative effects of sequential HFEs.	Same as spring HFEs	Implement as adaptive treatment when triggered and existing resource conditions allow
Fall HFEs longer than 96-hr duration	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Oct.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE longer than a 96-hr, 45,000-cfs flow Objective: Rebuild sandbars	Implement in each year triggered with duration limit in first test not to exceed 192 hr; limited to total of four tests in LTEMP period	Up to 250 hr depending on availability of sand	Same as fall HFEs	HFEs were not effective in building sandbars; resulting sandbars were no bigger than those created by shorter-duration HFEs; or unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations	Long Term Off-Ramp Conditions	Action if Successful
<i>Sediment Treatments (Cont.)</i>						
Reduced fluctuations (load-following curtailment) after fall HFEs ^c	Trigger: Fall HFE Objective: Reduce erosion of newly built sandbars after HFE	Implement after fall HFEs	To the end of the month in which the HFE occurred (up to 30 days in Oct. or Nov.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	Resulting sandbars were no bigger than those created without reduced fluctuation; or unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment in association with HFEs when existing resource conditions allow
<i>Aquatic Resource Treatments</i>						
Trout management flows	Trigger: Predicted high trout recruitment in the Glen Canyon reach Objective: Test efficacy of flow regime on trout numbers and survival of chub	Implement as needed when triggered; test may be conducted early in the 20-year period even if not triggered by high trout recruitment; contingent on Tribal consultation	Implemented in as many as 4 months (May–Aug.)	Same as load-following curtailment	Little or no reduction in trout recruitment after at least three tests; or unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment triggered by predicted high trout recruitment in Glen Canyon, taking into consideration Tribal concerns

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations	Long Term Off-Ramp Conditions	Action if Successful
<i>Aquatic Resource Treatments (Cont.)</i>						
Mechanical removal of rainbow trout in Little Colorado River reach	<p>Trigger: Number of trout in Little Colorado River reach and number of humpback chub</p> <p>Objective: Test efficacy of control on trout numbers and survival of chub</p>	Implement in each year triggered unless determined ineffective, contingent on Tribal consultation	Up to six monthly removal trips (Feb.–Jul.)	Same as load-following curtailment	Little or no reduction in trout density at the Little Colorado River; no population-level benefit on humpback chub; or unacceptable adverse impacts on chub population or other resources	Implement as adaptive treatment when triggered, taking into consideration Tribal concerns
Low summer flows (minimum daily mean 5,000 to 8,000 cfs) to target $\geq 14^{\circ}\text{C}$ at Little Colorado River confluence	<p>Trigger: Chub numbers are below trigger, water temperature has been $<12^{\circ}\text{C}$ for two consecutive years, and target temperature of $\geq 14^{\circ}\text{C}$ can only be achieved if drop to low flow</p> <p>Objective: Test efficacy of low summer flows on warming and humpback chub growth</p>	If needed, two to three tests would be conducted in second 10 years of 20-year period. Would not be implemented in first 10 years	3 months (Jul.–Sep.)	Same as load-following curtailment	No increase in growth and recruitment of humpback chub; increase in warmwater nonnative species or trout at the Little Colorado River; or unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when conditions allow

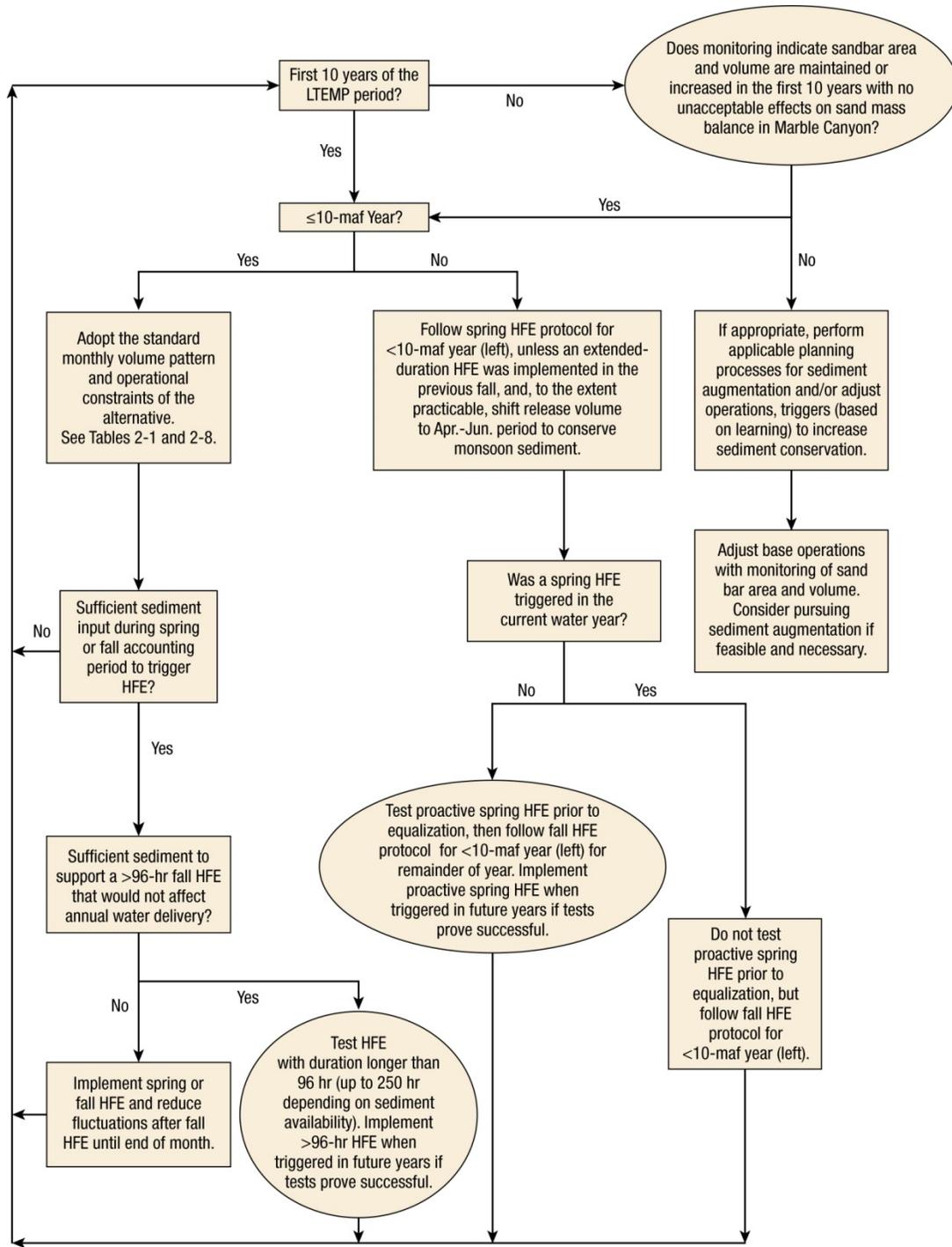
TABLE 2-9 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations	Long Term Off-Ramp Conditions	Action if Successful
<i>Aquatic Resource Treatments (Cont.)</i>						
Sustained low flows for benthic invertebrate production (2 days per week on weekends)	Trigger: None Objective: Improve food base productivity and EPT abundance or diversity	Not conducted during first 2 years of LTEMP; target two to three replicates	4 months (May–Aug.)	Same as load-following curtailment	No observed benefit to food base, trout fishery, or native fish; increase in warmwater nonnative species or trout at the Little Colorado River; or unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment in target months
<i>Riparian Vegetation Treatments</i>						
Non-flow vegetation restoration	Trigger: None Objective: Improve vegetation conditions at key sites	Not applicable	20 years if successful pilot phase	Potential unacceptable site-specific concerns related to key resources	Control and restoration techniques not effective or practical	Implement as adaptive treatment if invasive species can be reduced and native species increased

^a Annual determination by the DOI.

^b Temporary or permanent suspension if the DOI determines effects cannot be mitigated.

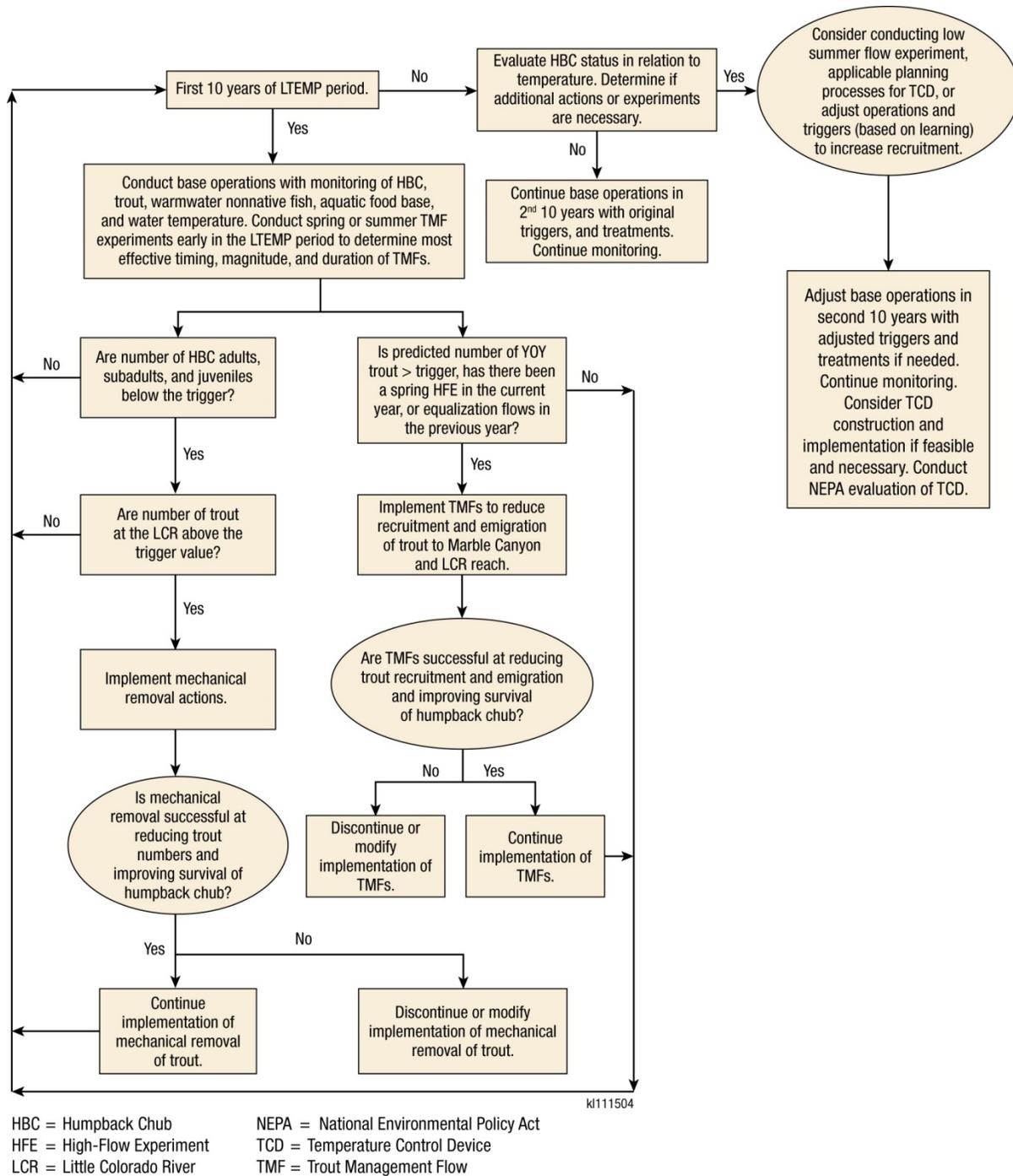
^c Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and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



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

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1
 2 **FIGURE 2-20 Decision Tree for Implementation of Sediment-Related Experimental**
 3 **Treatments under Alternative D (Implementation would be conditional on annual**
 4 **considerations presented in Table 2-9. If off-ramp conditions listed in Table 2-9 exist,**
 5 **related experimental treatments would be discontinued.)**
 6



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

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1
2 **FIGURE 2-21 Decision Tree for Implementation of Aquatic Resource-Related Experimental**
3 **Treatments under Alternative D (Implementation would be conditional on annual**
4 **considerations presented in Table 2-9. If off-ramp conditions listed in Table 2-9 exist, related**
5 **experimental treatments would be discontinued.)**
6

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

11
12 In implementing the experimental framework described here, and the associated decision
13 process shown in Figures 2-20 and 2-21, the DOI will exercise a formal process of stakeholder
14 engagement to ensure decisions are made with sufficient information regarding the condition and
15 potential effects on important resources. As an initial platform to discuss potential future
16 experimental actions, the DOI will hold GCDAMP annual reporting meetings for all interested
17 stakeholders; these meetings will present the best available scientific information and learning
18 from previously implemented experiments and ongoing monitoring of resources. As a follow up
19 to this process, the DOI will meet with the TWG to discuss the experimental actions being
20 contemplated for the year.

21
22 The DOI also will conduct monthly Glen Canyon Dam operational coordination meetings
23 or calls with the DOI bureaus (USGS, NPS, FWS, BIA, and Reclamation), Western, AZGFD,
24 and representatives from the Basin States and the UCRC. Each DOI bureau will provide updates
25 on the status of resources and dam operations. In addition, Western will provide updates on the
26 status of the Basin Fund, projected purchase power prices, and its financial and operational
27 considerations. These meetings or calls are intended to provide an opportunity for participants to
28 share and obtain the most up-to-date information on dam operational considerations and the
29 status of resources (including ecological, cultural, Tribal, recreation, and the Basin Fund). One
30 liaison from each Basin State and from the UCRC will be allowed to participate in the monthly
31 operational coordination meetings or calls.

32
33 To determine whether conditions are suitable for implementing or discontinuing
34 experimental treatments or management actions, the DOI will schedule implementation/planning
35 meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA and Reclamation), Western,
36 AZGFD, and one liaison from each Basin State and from the UCRC, as needed or requested by
37 the participants. The implementation/planning group will strive to develop a consensus
38 recommendation to bring forth to the DOI regarding resource issues as detailed at the beginning
39 of this section as well as including the status of the Basin Fund. The DOI will consider the
40 consensus recommendations of the implementation/planning group, but retains sole discretion to
41 decide how best to accomplish operations and experiments in any given year pursuant to the
42 ROD and other binding obligations.

43
44 DOI will also continue separate consultation meetings with the Tribes, AZGFD, the
45 Basin States, and UCRC upon request, or as required under existing Records of Decision.
46

1 The following text describes specific experimental development and implementation
2 processes for sediment, aquatic resources, and riparian vegetation. The overall approach attempts
3 to strike a balance between identifying the specific aspects of experiments deemed important and
4 providing flexibility in the implementation of those experiments that would allow for
5 consideration of specific resource conditions in the years when experiments are to be conducted.
6 As discussed above, rather than proposing a prescriptive approach to experimentation, an
7 adaptive management-based approach that is responsive and flexible would be used to adapt to
8 changing environmental and resource conditions and new information. The potential for
9 confounding interactions among individual experimental treatments is discussed when relevant
10 for each of the proposed treatments. Given the size of the project area, and the variability
11 inherent in the system, this pragmatic approach to experimentation is warranted, and although
12 confounding treatments are inevitable given the complexity of the experimental plan, they are
13 not expected to limit learning over the life of the LTEMP.

14 15 16 **Sediment-Related Experiments To Be Evaluated under Alternative D** 17

18 Under Alternative D, spring and fall HFEs would be implemented when triggered during
19 the 20-year LTEMP period using the same Paria River sediment input thresholds used under the
20 existing HFE protocol (Reclamation 2011b). HFE releases would be 1 to 96 hr long and between
21 31,500 and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria
22 River during the spring (December through March) or fall (July through October) accounting
23 periods, the maximum possible magnitude and duration of HFE that would achieve a positive
24 sand mass balance in Marble Canyon, as determined by modeling, would be implemented (see
25 Section 2.2.1 for a brief description of the existing HFE protocol).

26
27 Sand mass balance modeling is used to ensure that the duration and magnitude of an HFE
28 are best matched with the mass of sand present in the system during a particular release window.
29 The magnitude and duration of HFEs would not affect the total annual release from Glen Canyon
30 Dam. Reclamation would consider the total water to be released in the water year when
31 determining the magnitude and duration of an HFE.

32
33 Additional experiments under Alternative D include (1) reduced within-day fluctuations
34 (referred to as “load-following curtailment”) after fall HFEs (to the end of the month in which an
35 HFE occurs); (2) short-duration (24-hr) proactive spring HFEs in high-volume equalization years
36 prior to equalization releases; and (3) implementation of up to four extended-duration (>96-hr)
37 HFEs, up to 250 hr long, depending on sediment conditions. The pattern of transferring water
38 volumes from other months to make up the HFE volume will be addressed through a process like
39 that described in the previous section, and like that one will involve consultation with DOI
40 bureaus and Western. These experiments are similar to those proposed under Alternative C, but
41 differ in the specifics of implementation as discussed in this section.

42
43 If sediment resources are stable or improving, the combination of base operations, HFE
44 protocols, and other treatments would continue as prescribed for Alternative D. If sediment
45 resource conditions decrease to unacceptable levels during the LTEMP, alternate operations
46 would be evaluated, potentially including a feasibility study of sediment augmentation.

1 For all sediment experiments, testing would be modified or temporarily or permanently
2 suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or
3 (2) there were potential unacceptable adverse impacts on water delivery or key resources such as
4 humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural
5 properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout
6 fishery, recreation, and other resources (Table 2-9). Monitoring results would be evaluated to
7 determine whether additional tests, modification of experimental treatments, or discontinuation
8 of experimental treatments were warranted. Annual implementation of any experiments would
9 consider resource condition assessments and resource concerns using the interagency process
10 described in “Overall Implementation Process for Experiments under Alternative D” earlier in
11 this section.

14 ***Sediment-Triggered Spring HFEs under Alternative D***

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

27 After the first 2 years of the LTEMP period, spring HFEs would be implemented when
28 triggered, except in water years when an extended-duration fall HFE was conducted. Modeling
29 indicates that there may be sufficient sediment input for spring HFEs in about 26% of the years
30 in the LTEMP period.

32 Implementation of a spring HFE would provide important replication of the 2008 spring
33 HFE and aid in understanding the effect of spring HFEs on the trout population. It is possible
34 that the strong 2008 response was a result of the specific conditions present in 2008
35 (e.g., condition of the food base, trout population size). It is unclear whether implementation
36 under current conditions would produce the same result, and there is a good deal of learning that
37 could result from early implementation. Implementing a spring HFE early in the LTEMP period
38 when chub numbers are relatively high may also be a relatively low-risk option. To provide a
39 means of controlling trout recruitment following tests of spring HFEs, TMFs would be
40 experimentally implemented and tested for efficacy as early in the LTEMP period as possible
41 (see discussion of TMFs below). The apparent positive response of trout to the 2008 spring HFE
42 suggests that spring (or fall) HFEs might serve as a tool to purposely stimulate trout production
43 in the Glen Canyon reach if the trout population declines to unacceptable levels.

45 Spring HFEs may not be tested when there appear to be potential unacceptable impacts
46 on water delivery or key resources such as humpback chub, sediment, riparian ecosystems,

1 historic properties and traditional cultural properties, Tribal concerns, hydropower production
2 and the Basin Fund, the rainbow trout fishery, recreation, and other resources (Table 2-9). Any
3 implementation of sediment-triggered spring HFEs would consider resource condition
4 assessments and resource concerns using the interagency process described in “Overall
5 Implementation Process for Experiments under Alternative D” earlier in this section.
6
7

8 ***Proactive Spring HFEs under Alternative D***

9

10 GCMRC scientists identified proactive spring HFEs as a potential experimental treatment
11 to transport and deposit in-channel sand at elevations above those of equalization flows. These
12 HFEs would be tested only in years with high annual water volume (i.e., ≥ 10 maf), and modeling
13 suggests this would be a relatively rare treatment. Proactive spring HFEs would not be tested in
14 the first 2 years of the LTEMP period in order to allow for testing of TMFs prior to first
15 implementation. In addition, proactive spring HFEs would not be tested in years when there had
16 been a spring HFE earlier in the same water year; however, they could be performed in the same
17 water year following a sediment-triggered fall HFE (including an extended-duration fall HFE),
18 although they would be closely scrutinized and considered in that situation through consultation
19 described in “Overall Implementation Process for Experiments under Alternative D” earlier in
20 this section. A conservative first test would be a 24-hr 45,000-cfs release conducted in April,
21 May, or June. Duration in subsequent tests could be shortened depending on the observed
22 response during the first tests. It would be preferable to test proactive spring HFEs at least two to
23 three times in the 20-year LTEMP period, but being able to do so will be dependent upon annual
24 hydrology.
25

26 Modeling indicates that proactive spring HFEs would be triggered in about 10% of the
27 years in the LTEMP period. The first test would be carefully evaluated to determine whether
28 additional tests were warranted based on the efficacy of building and maintaining sandbars.
29 Proactive spring HFEs may not be tested when there appear to be potential unacceptable impacts
30 on water delivery or key resources such as humpback chub, sediment, riparian ecosystems,
31 historic properties and traditional cultural properties, Tribal concerns, hydropower production
32 and the Basin Fund, the rainbow trout fishery, recreation, and other resources (Table 2-9). Any
33 implementation of proactive spring HFEs would consider resource condition assessments and
34 resource concerns using the interagency process described in “Overall Implementation Process
35 for Experiments under Alternative D” earlier in this section.
36
37

38 ***Sediment-Triggered Fall HFEs under Alternative D***

39

40 The effects of sediment-triggered fall HFEs on trout recruitment are uncertain, but fall
41 HFEs are expected to have less effect on trout production than spring HFEs. The trout response
42 to the November 2004 HFE is not known, and no trout increase was observed from the
43 November 2012 or 2013 HFEs. However, factors affecting trout response to fall HFEs are not
44 well understood. Modeling for the DEIS considered the effect of fall HFEs on trout and modeled
45 fall HFEs in two ways: in one, the effect of fall HFEs was half as long as that of a spring HFE
46 (i.e., it affected trout production only in the water year in which it occurred); in the other, fall
47 HFEs had no effect on trout production. Modeling the effect of fall HFEs in these two ways had

1 an effect on the overall predicted number of trout produced, the number of out-migrants, and
2 ultimately their effect on humpback chub, but the relative performance among alternatives was
3 unchanged.

4
5 Modeling indicates fall HFEs would be triggered in about 77% of the years in the
6 LTEMP period. Testing fall HFEs is considered to be a relatively low-risk treatment due to the
7 lack of observed or documented trout response from previous fall HFEs, and would be
8 implemented when triggered during the entire LTEMP period unless new information indicated
9 fall HFEs were not effective in building sandbars, or there were unanticipated adverse effects.
10 Fall HFEs may not be tested when there appear to be potential unacceptable impacts on water
11 delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic
12 properties and traditional cultural properties, Tribal concerns, hydropower production and the
13 Basin Fund, the rainbow trout fishery, recreation, and other resources (Table 2-9). Any
14 implementation of sediment-triggered fall HFEs would consider resource condition assessments
15 and resource concerns using the interagency process described in “Overall Implementation
16 Process for Experiments under Alternative D” earlier in this section.

17
18
19 ***Extended-Duration Fall HFEs under Alternative D***

20
21 One modification to the HFE protocol that would be tested under Alternative D is
22 implementation of fall HFEs with durations longer than the current limit of 96 hr at various
23 release levels. Based on examination of the observed historical sediment input from the Paria
24 River, it was determined that HFEs up to 10.4 days in length (250 hr) could be supported before
25 exhausting seasonal sediment inputs and affecting water delivery requirements. GCMRC
26 scientists have suggested that increasing the duration of HFEs when sediment supply can support
27 a longer duration may lead to more sand being deposited at higher elevations, resulting in bigger
28 sandbars. Modeling indicates the sediment trigger for this treatment may be reached in 25% of
29 the years in the LTEMP period. There would be no more than four extended-duration fall HFEs
30 over the 20-year LTEMP period.

31
32 The duration of the first implementation of an extended-duration HFE would be limited
33 to no more than 192 hr (twice as long as the current limit of 96 hr). This duration is considered
34 long enough to produce a measurable result if the treatment represents an effective approach to
35 building sandbars under enriched sediment conditions. The duration of all tests would be based
36 on available sediment, current hydrology, reviews of available information, the expert opinion of
37 GCMRC and other Grand Canyon scientists, and consideration of potential effects on other
38 resources (e.g., food base, trout, humpback chub, hydropower, and Glen Canyon resources). If
39 feasible, monitoring would include real-time observations of sediment concentrations to
40 determine if sediment deposition continues throughout the duration of the extended HFEs. In
41 order to fully test the efficacy of these longer HFEs, several replicates would be desirable in the
42 20-year LTEMP period. Extended-duration HFEs would be considered successful and would be
43 continued up to a total of four times in the 20-year LTEMP period, as part of an adaptive
44 experimental treatment if there was a widespread increase in bar size relative to ≤ 96 -hr HFEs,
45 and if sand mass balance was not significantly compromised relative to the ability to maintain a
46 long-term equilibrium.

1 Extended-duration HFEs would not continue to be tested if they were not effective in
2 building sandbars, if resulting sandbars were no bigger than those created by shorter-duration
3 HFEs, or if unacceptable adverse impacts on the trout fishery, humpback chub population, or
4 other resources were observed. Water delivery issues would be considered before deciding to
5 implement an extended-duration HFE. Implementation would necessitate reducing water volume
6 in other months of the same water year. It is possible that in lower volume years there would not
7 be sufficient water available to support an extended-duration HFE, especially a 250-hr HFE. An
8 extended-duration HFE would not be implemented if water delivery would be affected. An
9 extended-duration HFE for 250 hr would result in a monthly total release of approximately
10 1.2 million ac-ft. In lower volume release years (e.g., 7.0 maf or 7.48 maf) the maximum
11 duration would be less than 250 hr. In addition, a sediment-triggered spring HFE would not be
12 conducted in the spring immediately following an extended-duration fall HFE. If an extended-
13 duration fall HFE was triggered but not implemented for any of the reasons described above, a
14 fall HFE 96 hr or less in duration would be implemented instead.

15
16 Resource status assessments would be considered prior to the decision for an extended-
17 duration HFE to evaluate the potential for unacceptable impacts on water quality in Lake Mead;
18 water delivery; or key resources such as humpback chub, sediment, riparian ecosystems, historic
19 properties and traditional cultural properties, Tribal concerns, hydropower production and the
20 Basin Fund, the rainbow trout fishery, recreation, and other resources (Table 2-9). Any
21 implementation of extended-duration fall HFEs would consider resource condition assessments
22 and resource concerns using the interagency process described in “Overall Implementation
23 Process for Experiments under Alternative D” earlier in this section.

24 25 26 ***Reduced Fluctuations after Fall HFEs under Alternative D***

27
28 Reduced fluctuations are considered a potential method of increasing the amount of sand
29 available for sandbar building and prolonging the persistence of sandbars created by HFEs. Used
30 in this context, “reduced fluctuations” mean flows in which hourly water release volumes would
31 be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to
32 accommodate regulation services. Regulation affects instantaneous operations that deviate above
33 and below the mean hourly flow without affecting mean hourly flow. Under Alternative D,
34 within-day fluctuations in hourly flows would be reduced to a within-day range of 2,000 cfs
35 (i.e., $\pm 1,000$ cfs of the mean daily flow).

36
37 After a fall HFE occurs, reduced fluctuations would be implemented until the end of the
38 month in which the HFE occurred. Reduced fluctuations after fall HFEs may not be tested when
39 there appear to be potential unacceptable impacts on water delivery or key resources such as
40 humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural
41 properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout
42 fishery, recreation, and other resources (Table 2-9). Any implementation of reduced fluctuations
43 after fall HFEs would consider resource condition assessments and resource concerns using the
44 interagency process described in “Overall Implementation Process for Experiments under
45 Alternative D” earlier in this section.

1 **Aquatic Resource-Related Experiments To Be Evaluated under Alternative D**
2

3 Under Alternative D, most experimental flow and non-flow actions would be triggered by
4 either estimated numbers of rainbow trout, a combination of estimated numbers of rainbow trout
5 and humpback chub, or measured water release temperature at Glen Canyon Dam, depending on
6 the action under consideration. Humpback chub triggers and trout triggers would be developed in
7 consultation with the FWS and AZGFD. These triggers may be modified based on
8 experimentation conducted early in the LTEMP period. Most aquatic resource-related
9 adjustments to operations and non-flow actions are similar to those proposed for aquatic
10 resources under Alternative C, but differ in the specifics of implementation as discussed in this
11 section and shown in Table 2-9. In addition to the experiments described in this section, and as
12 noted under the discussion of sediment-triggered spring HFEs above, the apparent positive
13 response of trout to the 2008 spring HFE suggests that spring (or fall) HFEs also might serve as a
14 tool to purposely stimulate trout production in the Glen Canyon reach if the trout population
15 declines to unacceptable levels.
16

17 Aquatic resource experiments that may be tested under Alternative D include (1) TMFs,
18 (2) mechanical removal of trout, (3) low summer flows, and (3) sustained low flows for benthic
19 invertebrate production. Aquatic resource experiments would seek to refine our understanding of
20 the impacts of equalization, HFEs, and TMFs on these resources. The primary uncertainty
21 surrounding HFEs revolves around the extent to which the seasonality of HFEs or the number of
22 adult rainbow trout determines the strength of rainbow trout recruitment.
23

24 For all aquatic resource experiments, testing would be modified or temporarily or
25 permanently suspended if (1) experimental treatments were ineffective at accomplishing their
26 objectives, or (2) there were potential unacceptable adverse impacts on water delivery or key
27 resources such as humpback chub, sediment, riparian ecosystems, historic properties and
28 traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the
29 rainbow trout fishery, recreation, and other resources (Table 2-9). Monitoring results would be
30 evaluated to determine whether additional tests, modification of experimental treatments, or
31 discontinuation of experimental treatments were warranted. Annual implementation of any
32 experiments would consider resource condition assessments and resource concerns using the
33 interagency process described in “Overall Implementation Process for Experiments under
34 Alternative D” earlier in this section.
35
36

37 ***Trout Management Flows under Alternative D***
38

39 TMFs (described in Section 2.2.3.2) are a potential tool that could be used to control
40 annual trout production in the Glen Canyon reach for purposes of managing the trout fishery and
41 for limiting emigration from the Glen Canyon reach to Marble Canyon and the Little Colorado
42 River reach. If resource conditions are appropriate, trout management flows may be tested under
43 Alternative D early in the experimental period, preferably in the first 5 years. These first tests
44 could be triggered by modeled trout recruitment levels or implemented without a trigger to test
45 the effectiveness of TMFs. The intent of these early tests would be to determine the effectiveness
46 of TMFs and a best approach to trout management. If TMFs are determined to be effective for

1 controlling trout numbers while minimizing impacts on other resources, they may be deployed as
2 an adaptive experimental treatment triggered by estimated trout recruitment.

3
4 It should be noted that several Tribes have expressed concerns about TMFs as a taking of
5 life within the canyon without a beneficial use. The Pueblo of Zuni has expressed concern that
6 the taking of life by trout stranding has an adverse effect on the Zuni value system. The joint-
7 lead agencies will continue to work with the Tribes regarding options for trout management, and
8 to determine the most appropriate means of mitigating impacts on Tribal values if TMFs are
9 implemented.

10
11 As many as three cycles/month for the 4-month period of May through August could be
12 tested, depending on the results of early tests. Aspects of TMF design that would be investigated
13 include:

- 14 • Duration of high flows needed to lure YOY rainbow trout into near-shore
15 habitats,
- 16 • Magnitude of the high flow that would be more effective in luring YOY trout
17 to near-shore habitats,
- 18 • Whether or not moving to high flows first is needed to reduce YOY trout
19 numbers (as opposed to simply dropping rapidly from normal flows to
20 minimum flows),
- 21 • Timing of TMF cycles during the May–August period of trout emergence, and
22
- 23 • Number of cycles necessary to effectively limit trout recruitment.
24
25
26
27
28

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

33
34 Certain aspects of TMF effectiveness can be addressed through observational studies
35 (e.g., the number of YOY rainbow trout observed in the near-shore environment in daily
36 increments after the high flow is initiated)⁷; others may be addressed through consideration of
37 the physical environment in Glen Canyon (i.e., what areas are inundated or exposed at different
38 flows). Ultimately, however, effectiveness would be judged based on comparison of fall trout
39 recruitment estimates to expectations based on prior years. It may take several years to make this
40 determination, depending on the strength of the response and the type of TMFs tested.
41 Ultimately, however, effectiveness would be based on the ability of TMFs to reduce recruitment
42 in and emigration from the Glen Canyon reach. The driving forces behind emigration are not

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

1 fully understood, but are expected to be related to population size and food base in the Glen
2 Canyon reach.

3
4 Even if TMFs can be used to control recruitment in the Glen Canyon reach, an increase in
5 trout reproduction in Marble Canyon could occur as a consequence of geomorphic changes in
6 that reach, thus limiting the effectiveness of TMFs in controlling trout numbers in the Little
7 Colorado River reach.

8
9 For the DEIS modeling, a trigger of 200,000 YOY trout was used to determine when
10 TMFs would be implemented. A regression equation based on annual volume, the variability in
11 flows from May through August, and the occurrence of a spring HFE was used to predict the
12 number of YOY. The actual trigger used could be higher or lower depending on the results of
13 experiments that will be conducted on the effectiveness of TMFs. In addition, the predictive
14 regression equation could be modified based on new information. The trigger and predictive
15 equation used would be modified as needed in an adaptive management context. Triggers for
16 implementation of TMFs would be developed in consultation with the AZGFD.

17
18 Monitoring of other resources, particularly food base and the physiologic condition of
19 adult rainbow trout, would also be considered. In addition, the number of YOY trout at the end
20 of the summer would be estimated to determine if it equals or exceeds the estimated number of
21 recruits needed to sustain the desired number of adult trout. If the estimated number of recruits is
22 less than the recruitment target, TMFs would be re-evaluated for modification before
23 implementation in subsequent years. It is anticipated that the trout population could rebound
24 from a 1-year drop below this target level.

25
26 As discussed in relation to sediment experiments above, there is concern among scientists
27 and stakeholders with regard to the risk associated with implementation of spring HFEs as
28 related to trout response and subsequent effects on the humpback chub population. For this
29 reason, TMFs would be implemented and tested for effectiveness as early in the LTEMP period
30 as possible, preferably before the first spring HFEs are triggered, even if not triggered by high
31 trout recruitment. TMFs could be implemented in years that feature a spring HFE and in the
32 water year that follows an equalization flow because of the expected positive effects of
33 equalization on rainbow trout recruitment. Any implementation of TMFs would consider the
34 status of the trout fishery prior to implementation. Modeling indicates TMFs would be triggered
35 by trout recruitment numbers in 32% of the years in the LTEMP period.

36
37 There is potential for confounding effects when coupling TMFs with HFEs. If trout
38 recruitment is still high after implementation of TMFs that follow HFEs, this would suggest
39 TMFs were not effective as designed for that trial. If recruitment is lower than expected after
40 TMF implementation, however, uncertainty will remain about whether an HFE failed to
41 stimulate trout recruitment or whether TMFs were effective in suppressing otherwise strong
42 recruitment. It may not be necessary to determine the underlying effect on trout numbers unless
43 TMFs have undesirable side effects on other resources or the trout population.

44
45 If TMFs are found to be highly effective in controlling trout recruitment and emigration
46 of trout, and emigration only occurs or primarily occurs immediately following high recruitment

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

8
9 Implementation would be based on ongoing evaluation of potential unacceptable impacts
10 on water delivery or key resources such as humpback chub, sediment, riparian ecosystems,
11 historic properties and traditional cultural properties, Tribal concerns, hydropower production
12 and the Basin Fund, the rainbow trout fishery, recreation, and other resources (Table 2-9). Any
13 implementation of TMFs would consider resource condition assessments and resource concerns
14 using the interagency process described in “Overall Implementation Process for Experiments
15 under Alternative D” earlier in this section.

16 17 18 ***Mechanical Removal of Rainbow and Brown Trout under Alternative D***

19
20 Experimental implementation of mechanical removal of rainbow and brown trout would
21 incorporate aspects of the protocol outlined in Reclamation’s Nonnative Fish Control EA, but
22 testing would be limited to upstream and downstream of the Little Colorado River reach
23 (potentially from RM 50–66). Mechanical removal would be triggered by both the number of
24 trout (high) and adult humpback chub (low). Triggers for trout removal are set in the Nonnative
25 Fish Control protocol and the FWS 2011 Biological Opinion at 760 trout between RM 63 and
26 RM 64.5, but this trigger and an appropriate removal strategy (frequency and timing of removal)
27 would be re-evaluated in consultation with the FWS and AZGFD under Alternative D. Modeling
28 conducted for the DEIS indicated that mechanical removal at this level was effective unless
29 immigration rates into the Little Colorado River reach were high. That modeling also suggested
30 that a “reverse trigger” that only implemented mechanical removal when immigration rates were
31 low could be more effective than the current one and could actually result in a need to remove
32 fewer trout over the long term. If local production of trout was occurring either in the Little
33 Colorado River reach or lower Marble Canyon (instead of immigration from upstream areas), it
34 may be important to mechanically remove trout when numbers are high.

35
36 Up to six monthly removal trips (February through July) would be implemented in each
37 year triggered. Testing would stop or the protocol would be modified if it was determined that
38 mechanical removal was not effective in maintaining low trout densities or did not result in a
39 substantial increase in humpback chub recruitment. Mechanical removal of trout would not be
40 conducted in years when there were potential unacceptable impacts on key resources including
41 humpback chub, cultural resources, and possibly others. Because mechanical removal is a non-
42 flow activity, there are fewer resources that could be affected by the action as compared to flow
43 experiments. Any implementation of mechanical removal would consider resource condition
44 assessments and resource concerns using the interagency process described in “Overall
45 Implementation Process for Experiments under Alternative D” earlier in this section.

1 The DOI recognizes that lethal mechanical removal is a concern for Tribes, particularly
 2 the Pueblo of Zuni, as a taking of life in the canyon. To the extent practicable, removal practices
 3 would include finding beneficial uses for removed fish similar to those associated with trout
 4 removal in Bright Angel Creek. The lead agencies will continue to consult with Tribes and other
 5 signatories to the National Historic Preservation Act Programmatic Agreement on this issue.
 6
 7

8 ***Low Summer Flows under Alternative D***
 9

10 Low summer flows could lead to warmer water temperatures in the Little Colorado River
 11 reach and further downstream, as well as contributing to enhanced growth rates of young
 12 humpback chub. It is thought that the potential benefit of an increase in temperature would be
 13 greatest if a water temperature of at least 14°C could be achieved, because these warmer
 14 temperatures could favor higher humpback chub growth rates (nearly 60% higher). For
 15 comparison, the July through September growth increments of YOY humpback chub are
 16 estimated to be 4, 7, 11, 14, and 17 mm at temperatures of 12, 13, 14, 15, and 16°C, respectively,
 17 based on a growth-temperature regression in Robinson and Childs (2001). Note that reduction in
 18 summer flows would necessitate increasing flows in other months relative to base operations
 19 (Table 2-10; Figure 2-22).
 20
 21

22 **TABLE 2-10 Flow Parameters for a Year with Low Summer Flows**
 23 **under Alternative D in an 8.23-maf Year^a**

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

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

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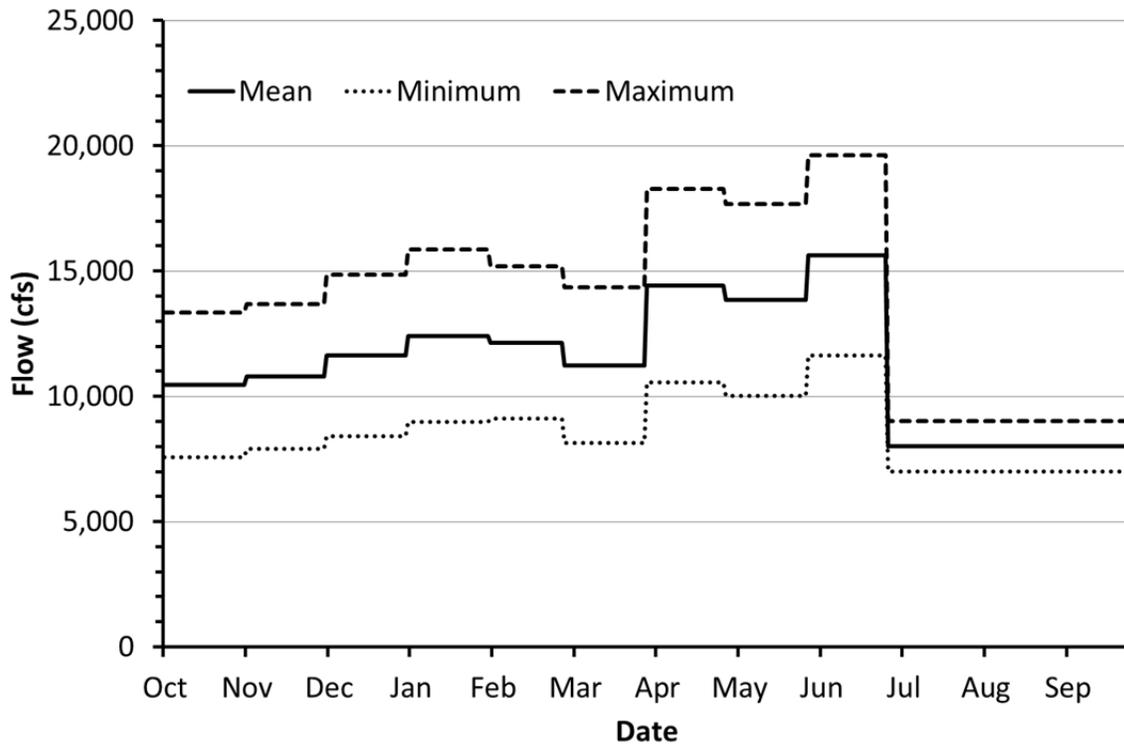


FIGURE 2-22 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-10

Testing of low summer flows would only be considered in the second 10-year period if testing was deemed appropriate and did not present potential unacceptable impacts on water delivery or on key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources (Table 2-9). If tested, low flows would occur for 3 months (July, August, and September). The probability of triggering a low flow experiment is considered quite low (about 7% of years), and it is unlikely that more than two replicates would be possible in the second 10 years of the LTEMP period.

Low summer flows could be implemented if the temperature at the Little Colorado River confluence would be below 14°C without low summer flows, but release temperature was sufficiently high that 14°C could be achieved at the Little Colorado River with the use of low summer flows.

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

1 Release temperatures fall into three categories for any temperature target: (1) too low to
2 achieve the target temperature at the Little Colorado River even at low flow; (2) high enough to
3 achieve the target temperature at the Little Colorado River only if low flows (5,000 to 8,000 cfs)
4 are provided; and (3) high enough to achieve target temperature at the Little Colorado River
5 regardless of the flow level. Low summer flows would only be triggered in years that fell into the
6 second category.
7

8 Implementation of a low summer flow experiment is complicated by two factors: the
9 earliest date at which it could be determined that a target temperature of at least 14°C could be
10 achieved in all 3 months, and the ability to release the remaining annual volume once that
11 determination is made. The earliest time a determination could be made would be in early April
12 of each year, and would be based on the April 1 forecast of reservoir elevation. Because low
13 summer flows would be implemented in the 3 months at the end of the water year, it is possible
14 that by the time a determination was made to conduct a low summer flow experiment, it may not
15 be possible to release enough water in the remainder of the spring to compensate for the low
16 flow period. A low summer flow experiment would only be tested in years when water delivery
17 goals could be met.
18

19 A first test of low summer flows would feature low flows of 8,000 cfs and relatively little
20 fluctuation ($\pm 1,000$ cfs per day). Depending on the results of the first test with regard to warming
21 and humpback chub response, the magnitude of the low flow could be adjusted up or down
22 (as low as 5,000 cfs), and the level of fluctuation also modified up to the range allowed under
23 Alternative D (i.e., $10\times$ monthly volume [in kaf] in July and August, and $9\times$ monthly volume
24 [in kaf] in September). Low summer flows would be considered successful if they produced
25 sufficient growth of YOY humpback chub that resulted in an increase in recruitment, but avoided
26 significant increases in warmwater nonnative fishes and trout unless those could be mitigated by
27 other actions. If the first test of low summer flows was determined to be unsuccessful, then
28 repeated tests would not be performed.
29

30 The first test of low summer flows will be determined to be successful or unsuccessful
31 based on an independent scientific panel review. If the first test was determined to be
32 unsuccessful (and it was determined to have been implemented properly without major
33 confounding factors), then additional tests would not be performed. Low summer flows would be
34 considered successful if they produced sufficient growth of YOY humpback chub and that
35 growth resulted in an increase in recruitment, but avoided significant increases in warmwater
36 nonnative fishes and trout. If it was determined to be successful, then additional low summer
37 flows would occur only when humpback chub population concerns warranted them. The
38 temperature target could be adjusted 1°C higher based on the results of the first test or the
39 limitations between predicted and measured temperatures. Any implementation of low summer
40 flows would consider resource condition assessments and resource concerns using the
41 interagency process described in “Overall Implementation Process for Experiments under
42 Alternative D” earlier in this section.
43

44 Implementation of low summer flows would be based on evaluations of potential
45 unacceptable impacts on water delivery or key resources such as humpback chub, sediment,
46 riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns,

1 hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other
2 resources (Table 2-9), as well as the risk of warmwater nonnative fish expansion or invasion
3 (e.g., the elevation of Lake Mead was high or the number of warmwater nonnative fish was
4 high). In addition, there are concerns related to Lake Mead water quality under certain conditions
5 that would be considered prior to implementation. Testing of low summer flows would stop if it
6 was determined that warmwater nonnative fish or trout responded favorably to the low flows and
7 resulted in adverse impacts on humpback chub.

8
9
10 ***Sustained Low Flows for Benthic Invertebrate Production under Alternative D***

11
12 Mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera),
13 collectively referred to as EPT, are important components of a healthy aquatic food base, but are
14 notably absent from the Glen and Marble Canyon reaches and very low in abundance and
15 diversity in the Grand Canyon. GCMRC has hypothesized that EPT taxa are recruitment limited,
16 because daily flow fluctuations to meet hydropower demand cause high egg mortality, and the
17 absence of EPT has an adverse effect on the carrying capacity and condition of the trout fishery
18 and native fish communities. EPT are thought to be recruitment limited because Glen Canyon
19 Dam fluctuations create a large varial (intermittently wetted) zone along shorelines. Because the
20 Colorado River in Glen, Marble, and Grand Canyons is canyon-bound and the tributaries that
21 join the river all have comparatively low flow, the size of the varial zone does not appreciably
22 decrease with distance downstream. Thus, although water temperature regimes become more
23 naturalized with distance downstream, the effect that daily flow fluctuations to meet hydropower
24 demand have on the stability of shoreline habitat does not attenuate much with distance from the
25 dam.

26
27 This hypothesis attributes the absence of EPT and the poor health of the invertebrate
28 assemblage to the width of the varial zone, similar to earlier investigations (Blinn et al. 1995),
29 but focuses on the effects unstable shorelines have on the eggs of these species. This hypothesis
30 assumes that egg-laying by EPT occurs principally along shorelines. According to the
31 hypothesis, EPT taxa downstream of Glen Canyon Dam are recruitment limited, because daily
32 flow fluctuations to meet hydropower demand negatively affect habitat quality along the
33 shorelines where egg laying is assumed to occur.

34
35 To test this hypothesis, steady flows would be provided every weekend from May
36 through August (34 days total). The flow on weekends would be held to the minimum flow for
37 that month, which would ensure that the insect eggs laid during weekends would never be
38 subjected to drying due to lower water levels at any point prior to larval development. If the
39 hypothesis is true, there would be an increase in insect production due to the reproductive
40 success of insects that laid eggs during weekends. No change in monthly volumes, ramping rates,
41 or the daily range in flow during weekdays would be required for this experiment. To offset the
42 smaller water releases that would occur during weekends within a given month, larger releases
43 would need to occur during the weekdays within a given month.

44
45 Effects of the tests would be evaluated using observation to determine the location where
46 insect eggs are deposited and the emergence rates of species. Depending on the outcome of the

1 first tests, the experiment would either be continued or not, and could also be discontinued in
2 future years if there were undesirable effects to other resources. There is also the strong
3 possibility that implementation would result in confounding interactions with TMF experiments.
4 For this reason, tests of sustained low flows for benthic invertebrate production would not be
5 conducted during the first 2 years of the LTEMP period and may not be conducted in years when
6 TMFs were being tested unless a compatible experimental design that included both tests was
7 developed.
8

9 As for other experiments, a decision to implement sustained low flows for benthic
10 invertebrate production in year would be based on evaluations of potential unacceptable impacts
11 on water delivery or key resources such as humpback chub, sediment, riparian ecosystems,
12 historic properties and traditional cultural properties, Tribal concerns, hydropower production
13 and the Basin Fund, the rainbow trout fishery, recreation, and other resources (Table 2-9). Any
14 implementation of sustained low flows for benthic invertebrate production would consider
15 resource condition assessments and resource concerns using the interagency process described in
16 “Overall Implementation Process for Experiments under Alternative D” earlier in this section.
17
18

19 **2.2.5 Alternative E**

20
21 The objective of Alternative E is to provide for recovery of the humpback chub while
22 protecting other important resources including sediment, the rainbow trout fishery at Lees Ferry,
23 aquatic food base, and hydropower resources. Alternative E features a number of condition-
24 dependent flow and non-flow actions that would be triggered by resource conditions (Table 2-2).
25 The alternative uses decision trees to identify when a change in base operations or some other
26 action is needed to protect resources. Of particular focus under Alternative E are changes in
27 sediment input, humpback chub numbers and population structure, trout numbers, and water
28 temperature. The Basin States submitted this alternative for analysis and consideration in the
29 LTEMP DEIS.
30

31 Some aspects of Alternative E originally proposed by the Basin States were not included
32 in the alternative evaluated in the DEIS. These include new infrastructure in the form of a pump-
33 back system that would be used to pump water from the mainstem Colorado into the Paria River
34 to mobilize fine sediment that would then flow into the Colorado River and increase turbidity to
35 reduce the predation efficiency of trout on young humpback chub. The Basin States also
36 proposed implementation of rapid-response HFEs that would be implemented by timing high
37 releases from Glen Canyon Dam to coincide with sediment inputs from the Paria River. See
38 Section 2.4 for a discussion of elements considered but dismissed from analysis in the LTEMP
39 DEIS. Similarly, the LTEMP team modified some aspects of the original alternative, such as the
40 frequency of lower summer flows, for modeling purposes.
41
42

43 **2.2.5.1 Base Operations under Alternative E**

44
45 Under Alternative E, monthly volumes would closely follow the monthly hydropower
46 demand as defined by the contract rate of delivery (Table 2-11). The total monthly release

1

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

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

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

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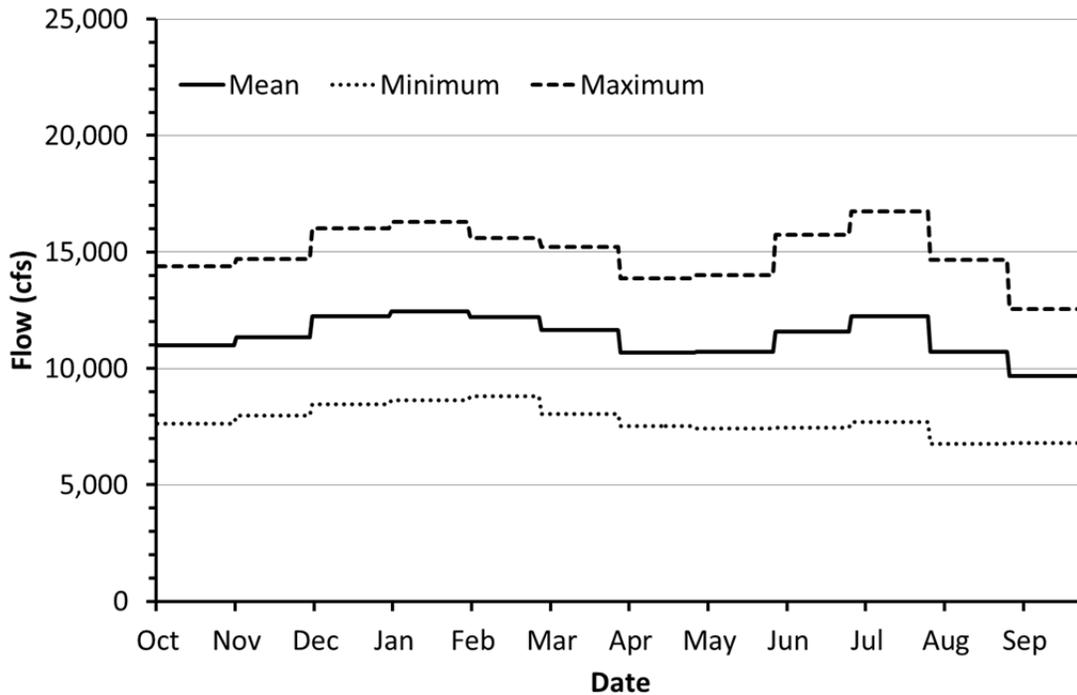
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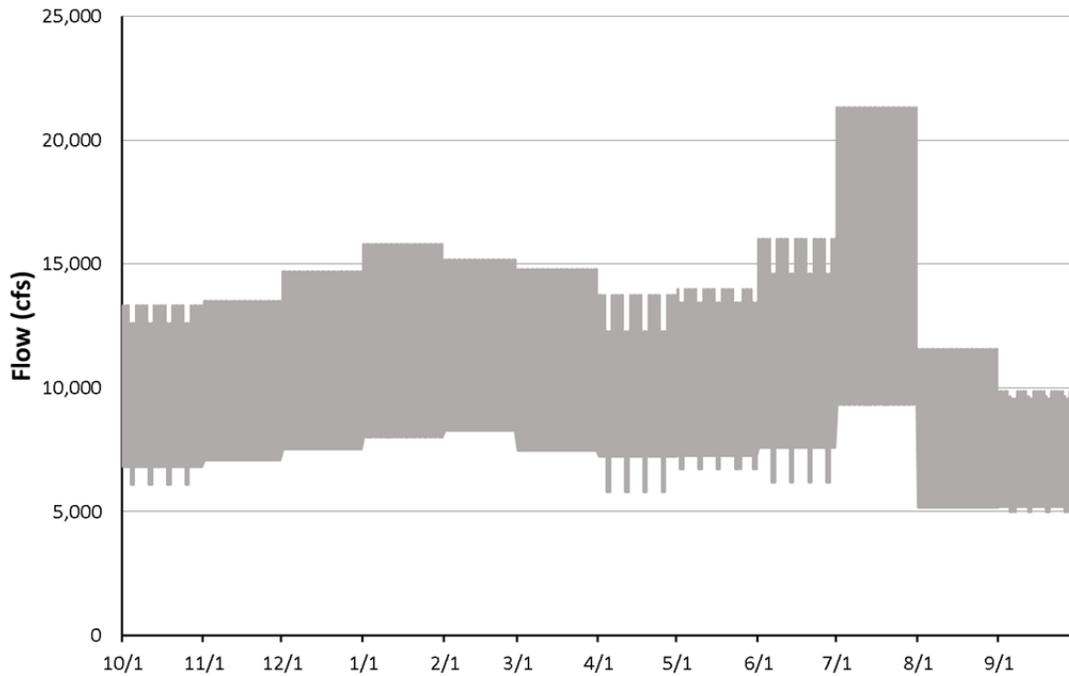
volume of October, November, and December, however, would be equal to that under Alternative A to minimize the possibility of the operational tier differing from that of Alternative A as established in the Interim Guidelines (Reclamation 2007a). In addition, lower monthly volumes (relative to Alternative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

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



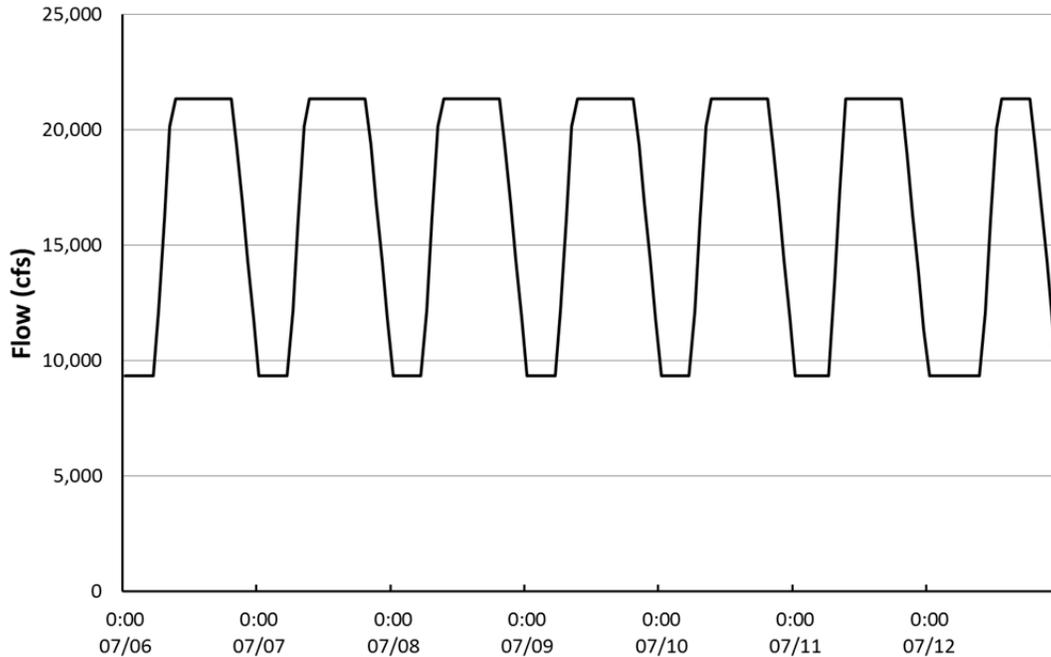
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FIGURE 2-23 Mean, Minimum, and Maximum Daily Flows under Alternative E in an 8.23-maf Year Based on the Values Presented in Table 2-11



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



1

2 **FIGURE 2-25 Simulated Hourly Flows under Alternative E for a Week in July in an**
3 **8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday**
4 **and ends on Sunday.)**

5

6

7

2.2.5.2 Experimental Framework for Alternative E

8

9

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

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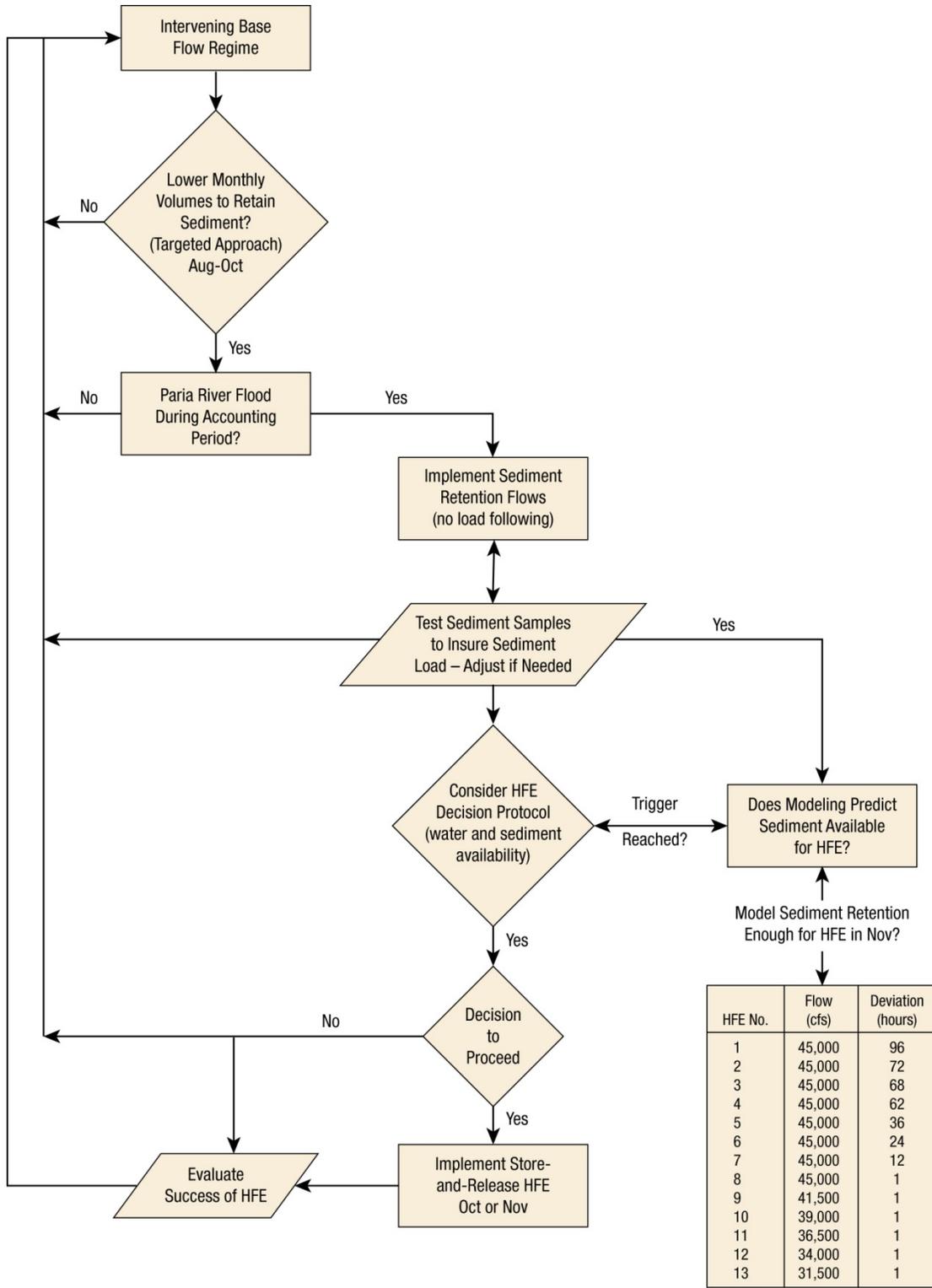
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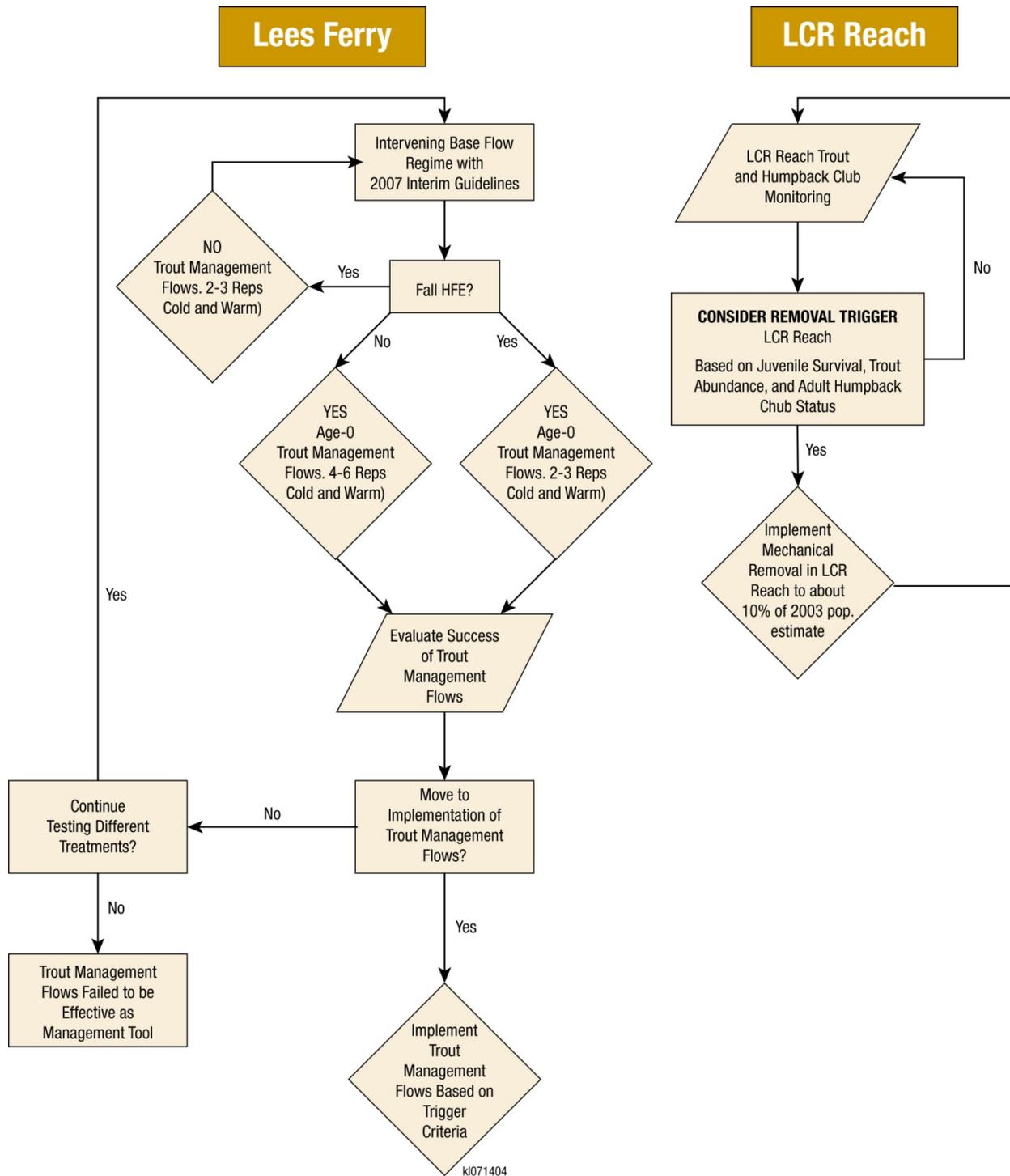
Base operations under Alternative E would be experimentally modified in response to changes in resource conditions or the need for equalization as specified under the 2007 Interim Guidelines (Reclamation 2007a). The most important experiments relate to (1) implementation of HFEs in response to sediment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



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



1
 2 **FIGURE 2-27 Decision Tree for Trout-Related Actions under Alternative E (Figure 2 in original**
 3 **Basin States submittal)**
 4

1 **Sediment-Related Experiments To Be Evaluated under Alternative E**
2

3 Under Alternative E, spring and fall HFEs would be implemented when triggered using
4 the same Paria River sediment input thresholds used under the existing HFE protocol
5 (Reclamation 2011b). HFE releases would be 1 to 96 hr long and between 31,500 and 45,000 cfs.
6 Depending on the cumulative amount of sediment input from the Paria River during the spring
7 (December through March) or fall (July through October) accounting periods, the maximum
8 possible magnitude and duration of HFE that would achieve a positive sand mass balance in
9 Marble Canyon, as determined by modeling, would be implemented (see Section 2.2.1 for a brief
10 description of the existing HFE protocol).
11

12 Under Alternative E, only fall HFEs would be conducted during the first 10-year period.
13 This delay of implementation of spring HFEs is intended to allow for the testing of TMFs to
14 control trout numbers and emigration rates, and is based on the response of the trout population
15 to the spring HFE of 2008.
16

17 Under Alternative E, daily fluctuations for load-following would be reduced (except for
18 instantaneous increases or decreases in flow to provide regulation services)⁸ after significant
19 sediment input (sufficient input to trigger an HFE) from the Paria River in August, September, or
20 October to increase the amount of sediment available for transport and deposition by fall HFEs.
21 These reduced fluctuations would occur until an HFE was implemented or a decision to not
22 implement an HFE was made. Under Alternative E, within-day fluctuations in hourly flows
23 would be reduced to a within-day range of 2,000 cfs (i.e., $\pm 1,000$ cfs of the mean daily flow).
24

25 During high-volume (≥ 10 -maf release volume) release years (i.e., equalization years), an
26 HFE would be conducted quickly (i.e., days) following an unusually large input of sediment
27 from the Paria River to redistribute the new sediment from the main river channel before
28 high-volume releases can transport it downstream. This “quick response” HFE is different from
29 the proactive spring HFEs proposed under Alternatives C and D because it is sediment-triggered;
30 could occur in the spring, summer, or fall of the year; and would not be limited in duration to
31 24 hr.
32

33
34 **Aquatic Resource-Related Experiments To Be Evaluated under Alternative E**
35

36 Mechanical removal of trout would be conducted at the confluence of the Little Colorado
37 River under certain conditions (i.e., low survival rate of juvenile humpback chub, trout
38 abundance exceeds the level seen in 2003 of about 6,900 individuals in the Little Colorado River
39 reach (RM 56.3 and RM 65.7), or the number of humpback chub adults drops by
40 1,000 individuals (during the same time the abundance of trout exceeds 690 in the same reach).
41 The removal protocol would follow the Nonnative Fish Control Protocol (Reclamation 2011a).
42

⁸ Although instantaneous changes in flows could occur within an hour to provide for regulation services, these flow changes would not affect the mean hourly flow.

1 Alternative E would evaluate potential methods for using releases (TMFs) from Glen
2 Canyon Dam to reduce production of YOY rainbow trout to improve the quality of the Glen
3 Canyon trout fishery and potentially help conserve humpback chub and other native fishes.
4

5 This strategy has two potential benefits: (1) flow manipulations are likely to be much less
6 expensive and intrusive than large-scale mechanical removal efforts downstream, and (2) trying
7 to manage trout densities in the Little Colorado River reach without reducing trout production
8 upstream will be difficult to overcome during years with high production (e.g., trout response to
9 2008 HFE and response to 2011 high steady flows). The goal is to develop a management action
10 based on condition-dependent criteria. Key metrics for a high-quality trout fishery would need to
11 be developed in consultation with the AZGFD, such as targets for adult and juvenile numbers,
12 individual fish condition, YOY numbers, and information and value determined through creel
13 surveys. TMFs could be used to help attain these goals with other management tools employed
14 by the AZGFD and the NPS. TMF treatments should address the following:
15

- 16 • Evaluate the potential for utilizing changes in down-ramp rates to strand or
17 displace juvenile trout and reduce recruitment,
18
- 19 • Evaluate different types and magnitudes of TMFs, and
20
- 21 • Determine whether flow and non-flow actions at Lees Ferry would be
22 effective in improving the Lees Ferry trout fishery.
23

24 TMFs would be tested in a 2×2 factorial design with HFEs over a 20-year period to
25 evaluate their potential effectiveness in reducing trout recruitment levels in the Glen Canyon
26 reach over a variety of environmental conditions. The status of the trout fishery would be
27 considered in any decision to proceed with implementation of TMFs in a given year. The goal is
28 to develop management tools that are robust to a range of natural and human caused conditions.
29 The following treatment combinations would be implemented with a goal of achieving two to
30 three replicates for each combination under warm and cold temperature conditions over the
31 20-year LTEMP period:
32

- 33 • No fall HFE and no TMF, to measure trout recruitment with neither factor in
34 place;
35
- 36 • No fall HFE, but with a TMF, to test effects of TMFs alone;
37
- 38 • Fall HFE, but no TMF, to test effects of HFEs alone; and
39
- 40 • Both fall HFE and TMF, to test the effects of both in the same year.
41

42 Two options for implementation would be considered (1) begin with moderate treatments
43 (e.g., one cycle); or (2) begin with more robust treatments (e.g., three or more cycles) to establish
44 easily observable results. With this latter approach, successive treatments would evaluate more
45 moderate treatments if the first tests showed an effect.
46

1 At least four types of TMFs would be evaluated: (1) YOY stranding and displacement
2 flows from May through June, (2) YOY stranding and displacement flows from July through
3 August, (3) YOY stranding and displacement flows without moving to high flows
4 (e.g., 20,000 cfs) prior to dropping to a minimum, and (4) flow reductions applied only at night
5 to the above scenarios with the objective of reducing food base impacts from desiccation.
6

7 YOY stranding and displacement flows would consist of 3 days at steady 20,000 cfs
8 followed by a rapid drop (unrestricted down-ramp rate) to 5,000 or 8,000 cfs to be held for 6 hr
9 during daylight hours (6 a.m.–noon). Three such cycles would be conducted over the month. A
10 3-day flow cycle would be followed by 7 days of normal flows, and this 3- to 7-day pattern
11 would be repeated three times over the month. This option would include tests of this method in
12 May and June, and then in July and August if sediment retention flows were not in effect (see
13 Figure 2-15 for an illustration of TMFs).
14

15 A test without moving to high flows first would determine if it is necessary to attract trout
16 to higher elevations (e.g., steady 20,000 cfs) before a rapid drop. Trout generally reside at the
17 normal minimum flow (Korman and Campana 2009). Thus, they may be susceptible to a rapid
18 drop in flow without the need to raise flows for an extended period beforehand. This test would
19 stabilize flows near the normal minimum (within the varial zone), and would then apply a rapid
20 down-ramp below the minimum.
21

22 If reservoir elevations are not variable enough during the first 10 years to produce years
23 with warm releases, a steady flow test aimed at achieving warmer temperatures would be
24 considered. If the evaluation is warranted, implementation would be conditioned on the status of
25 the humpback chub and other critical resources. A low summer flow experiment would not be
26 conducted at a time when the humpback chub population is low or declining. Under
27 Alternative E, a low summer flow experiment would only be conducted in a warm release year to
28 increase contrast with more typical cold water years.
29

30 The transition in flow volume from one month to the next can be substantial. Low-
31 volume months, such as a 600-kaf month, can be followed by a month that exceeds 900 kaf.
32 These large transitions may have a negative impact on productivity of the aquatic food base
33 (i.e., organisms including algae, plants, and invertebrates that serve as the foundation of the
34 aquatic food web). Alternative E would include a stepped transition between months when
35 substantial differences in the amount of water releases occur. The decision rules for transition
36 flows would need to be developed to take into account the difference in volume that would
37 trigger these flows, and the amount of time necessary to provide suitable transition to minimize
38 impacts on the food base.
39

40 **2.2.6 Alternative F**

41 The objective of Alternative F is to provide flows that follow a more natural pattern
42 while limiting sediment transport and providing for warming in summer months. In keeping with
43 this objective, Alternative F does not feature some of the flow and non-flow actions of the other
44 alternatives.
45
46

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

8
9 Under Alternative F, peak flows would be provided in May and June, which corresponds
10 well with the timing of the pre-dam peak. The overall peak flow in an 8.23-maf year would be
11 20,000 cfs (scaled proportionately in drier and wetter years), and would include a 24-hr
12 45,000-cfs flow at the beginning of the spring peak period (e.g., on May 1) if there was no
13 triggered spring HFE in same year, and a 168-hr (7-day) 25,000 cfs flow at the end of June.
14 Following this peak, there would be a rapid drop to the summer base flow. The initial annual
15 45,000-cfs flow would serve to store sediment above the flows of the remainder of the peak, thus
16 limiting sand transport further downstream and helping to conserve sandbars. The variability in
17 flows within the peak would also serve to water higher-elevation vegetation.

18
19 Low base flows would be provided from July through January. These low flows would
20 provide for warmer water temperatures, especially in years when releases are warm, and would
21 also serve to reduce overall sand transport during the remainder of the year.

22
23 Under Alternative F, the only adjustment to base operations would be sediment-triggered
24 HFEs implemented according to the HFE protocol (Reclamation 2011b) for the entire LTEMP
25 period. There would be no mechanical removal of trout or TMFs. However, the rapid drop from
26 peak flow to base at the end of June could incidentally serve much the same function as a TMF,
27 thus acting to reduce the overall high trout production rates expected under a steady flow regime.

28
29 Other than testing the effectiveness of HFEs as implemented under the HFE protocol,
30 there would be no explicit experimental or condition-dependent triggered actions under
31 Alternative F. As with other alternatives, an ongoing monitoring program would be used to
32 determine the response of resources to operations, and adjustments to those operations would be
33 made consistent with adaptive management.

34 35 36 **2.2.7 Alternative G**

37
38 The objective of Alternative G is to maximize the conservation of sediment, in order to
39 maintain and increase sandbar size. The alternative is based on the hypothetical best-case
40 scenario suggested by Wright, Schmidt et al. (2008) for conservation of sand inputs from
41 tributaries downstream of Glen Canyon Dam. Under Alternative G, flows would be delivered in
42 a steady pattern throughout the year with no monthly differences in flow other than those needed
43 to adjust operations in response to changes in forecast and other operating requirements such as
44 equalization (Tables 2-1 and 2-13; Figure 2-29). In an 8.23-maf year, steady flow would be
45 approximately 11,400 cfs.

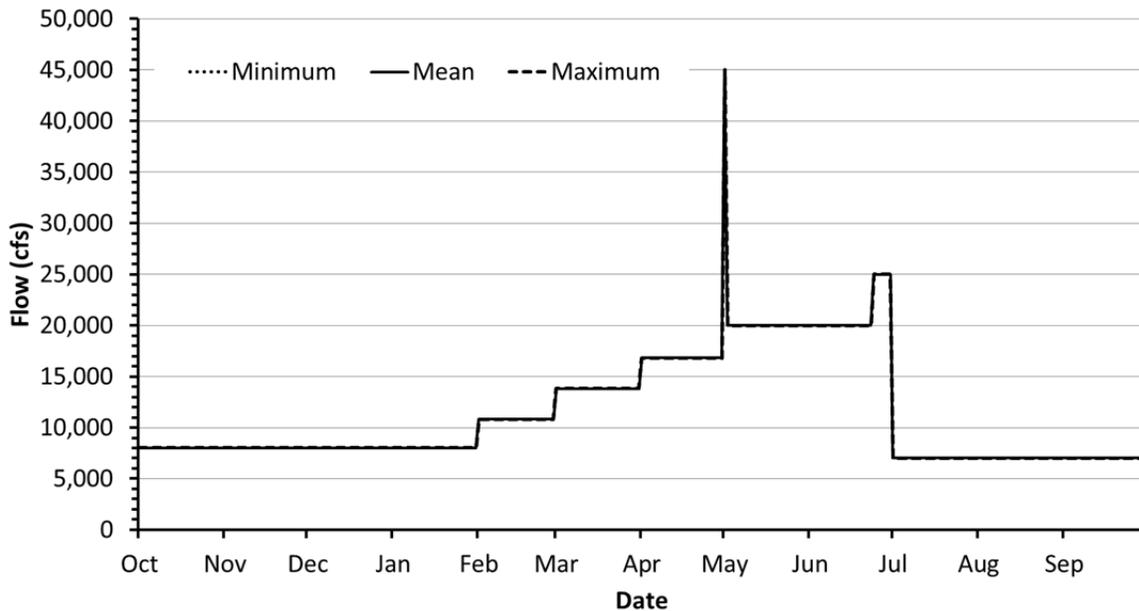
1

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

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

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

2
3



4

5

6

7

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

1

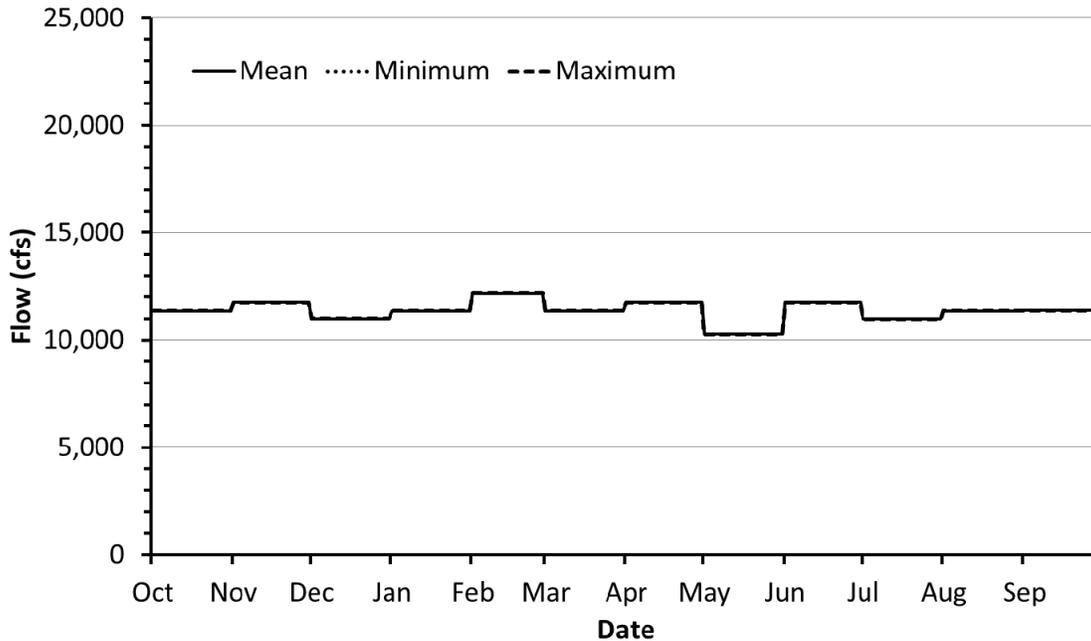
TABLE 2-13 Flow Parameters under Alternative G in an 8.23-maf Year^a

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

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

^b Variation among months reflects adjustments based on changing forecasts.

2
3



4

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

6

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

9
10 Under Alternative G, mechanical removal of trout would be implemented consistent with
11 the Nonnative Fish Control protocol (Reclamation 2011a) in the Little Colorado River reach.
12 Testing and implementation of TMFs as triggered by trout recruitment would occur as described
13 for Alternative C (Section 2.3.3.3).

14 15 16 **2.3 ALTERNATIVES CONSIDERED AND ELIMINATED FROM DETAILED STUDY**

17
18 During the scoping and analysis periods for the LTEMP DEIS, a number of alternative
19 concepts were either (1) developed and explored by the DOI's LTEMP team; (2) developed as
20 complete alternative proposals by the Cooperating Agencies or other stakeholders; or
21 (3) suggested by the public as alternatives that should be included in the LTEMP DEIS. Four of
22 the alternative concepts developed by the DOI's LTEMP team are described in Section 2.3
23 (Alternatives C, D, F, and G). Also described in Section 2.3 are two complete alternative
24 proposals submitted by stakeholders. Alternative E was submitted by the Basin States and
25 Alternative B was submitted by CREDA, a non-profit association of energy customers of the
26 Colorado River Storage Project, in response to the DOI's request to all stakeholders for
27 alternative concepts. Other alternatives are identified below with an explanation of why they
28 were not included as an alternative in the DEIS.

29 30 31 **2.3.1 Modified Low Fluctuating Flows with Extended Protocols**

32
33 The DOI's LTEMP team identified an alternative that would be comparable to
34 Alternative A, but that would extend the existing HFE and Nonnative Fish Control protocols past
35 their current expiration date of 2020 through the entire LTEMP period. This alternative was in
36 part identified to enable a more direct comparison of impacts with the remaining alternatives that
37 would extend the protocols through the LTEMP period. Alternative A, by definition, would only
38 implement existing decisions up to their expiration dates. Preliminary analyses indicated that this
39 alternative would perform similarly to Alternative A, especially for hydropower generation value
40 (based on monthly release volumes and daily flow fluctuations), and would be similar to
41 Alternative E with respect to humpback chub, trout, and sediment resources (because of
42 alternative-specific flow fluctuations and the frequency of HFEs). The analysis of the seven
43 alternatives evaluated in the DEIS evaluates a reasonable range of possible operational and
44 experimental variations, including those of this alternative, without requiring additional detailed
45 analysis for NEPA compliance purposes.

1 **2.3.2 Naturally Patterned Flow Alternative**
2

3 A Naturally Patterned Flow Alternative, similar to the Historic Pattern Alternative,
4 described in the 1995 EIS (Reclamation 1995), was identified by the DOI's LTEMP team as a
5 possible alternative early in the LTEMP DEIS process. Under this alternative, flows would vary
6 from month to month in conformance with the historic flow pattern, and would not include daily
7 fluctuations. HFEs would be sediment triggered, but their timing would be shifted to conform to
8 natural flood timing. Minimum flows could be lower than the current minimum, and maximum
9 flows as high as full bypass, scaled for the annual hydrologic condition. Transitions between
10 months would be relatively smooth, with established limitations on the rate of change
11 between days.
12

13 Preliminary modeling indicated that sand transport under this alternative, as originally
14 defined, would be far higher than under other alternatives. When originally conceived, this
15 alternative featured sediment augmentation as a critical element. Without sediment augmentation
16 (see rationale for not including sediment augmentation or other new infrastructures in
17 alternatives in Section 2.4.1), estimated sand transport would be too great to sustain downstream
18 sediment resources, and, as a consequence, this alternative was considered to not meet the
19 purpose, need, and objectives of the LTEMP. High rates of erosion were also identified for the
20 Historic Pattern Alternative in the 1995 EIS (Reclamation 1995), and considered as the primary
21 reason for eliminating it from further consideration. It should be noted that Alternative F was
22 developed by the DOI in response to the findings of the preliminary analysis of the Naturally
23 Patterned Flow Alternative, and was included in the DEIS to provide an alternative that achieved
24 the original objectives of the Naturally Patterned Flow Alternative while reducing overall
25 sediment transport, and thus, meeting the purpose, need, and objectives of the LTEMP.
26
27

28 **2.3.3 Seasonal Fluctuations with Low Summer Flow Alternative**
29

30 The Seasonal Fluctuations with Low Summer Flow Alternative would feature low
31 summer (July through September) flows each year, and was developed by the DOI's LTEMP
32 team to provide warmer water temperatures for native fish and other aquatic resources. Excess
33 water volume not released in the summer would be released in the winter (December through
34 February) and late spring (May and June). Fluctuations would be low in the summer (2,000 cfs
35 daily range), but would conform to MLFF-level fluctuations the remainder of the year. The
36 alternative would use the existing HFE and Nonnative Fish Control protocols for the entire
37 LTEMP period. Preliminary analyses for this alternative were completed, but it was not included
38 as an LTEMP alternative because the analyses suggested that the alternative did not perform
39 better than others with regard to impacts on native fish populations and other aquatic resources.
40 This is largely a consequence of the marginal gains in temperature (about 1 or 2°C at the Little
41 Colorado River confluence) that are expected to occur under low flows. Since the alternative did
42 not meet its intended objectives, there was no compelling reason to include it as an alternative in
43 the DEIS. Other alternatives, such as Alternatives C, D, and E, were determined to provide
44 benefits to native fish and aquatic resources, and therefore met the objectives of the Seasonal
45 Fluctuations with Low Summer Flow Alternative.
46

1 **2.3.4 Grand Canyon First! Alternative**
2

3 A “Grand Canyon First!” Alternative was proposed as an alternative concept in a number
4 of public scoping comments. In this alternative, consideration of the ecology and wildlife of
5 Grand Canyon would be the paramount consideration, restoring Grand Canyon to its historical
6 state to the extent possible. This alternative would recognize the Grand Canyon Protection Act
7 (GCPA) as the primary source to inform the LTEMP DEIS, and the operations of Glen Canyon
8 Dam should help to preserve the natural and cultural resources of Grand Canyon. Public
9 comment provided objectives but not an operational regime, non-flow actions, or experimental
10 plan to achieve those objectives; therefore, this alternative was not sufficiently well-defined to
11 include as an LTEMP alternative. Although this concept was not included as an alternative in the
12 DEIS, all LTEMP alternatives include many of the concepts that are in this proposal; for
13 example, operations to achieve sediment and native fish objectives are included in LTEMP
14 alternatives including Alternatives C, D, E, F, and G.
15
16

17 **2.3.5 Species Community and Habitat-Based Alternative**
18

19 Several members of the public suggested a Species Community and Habitat-Based
20 Alternative be included in the LTEMP DEIS. This proposed alternative concept was intended to
21 contribute to the conservation or recovery of endangered or extirpated species, such as the
22 humpback chub, razorback sucker, southwestern willow flycatcher, and Kanab ambersnail. It
23 would also contribute to the conservation of other non-listed aquatic and riparian species
24 (including flannelmouth sucker, bluehead sucker, and speckled dace) to reduce the need to list
25 them under the ESA. This would include an ESA Recovery Implementation Program focused on
26 supporting native species communities that ensures that their habitat-based needs are met. This
27 alternative would include a management program for the trout at Lees Ferry that also provides
28 for protection of humpback chub and other native fish populations downriver, and a quality
29 recreational fishery at Lees Ferry. Public comment provided objectives, but not an operational
30 regime, non-flow actions, or experimental plans to achieve those goals, and, therefore, was not
31 sufficiently well-defined to include as an LTEMP alternative. Although this concept was not
32 included as an alternative in the DEIS, other elements of the concept, such as operations to
33 achieve sediment, native fish, and trout management objectives, are included in several
34 alternatives including Alternatives B, C, D, E, F, and G. Each of these LTEMP alternatives
35 identifies operations to protect existing ecological resources.
36
37

38 **2.3.6 Stewardship Alternative**
39

40 During public scoping, commenters suggested consideration of a Stewardship Alternative
41 that utilized a flow regime that would best serve Grand Canyon and be aligned with the GCPA,
42 with no consideration given to hydropower. Commenters provided objectives but not an
43 operational regime, non-flow actions, or experimental plan to achieve those objectives, and,
44 therefore, this alternative was not sufficiently well-defined to include as an LTEMP alternative.
45 In addition, the suggestion that hydropower generation should not be considered as an objective
46 is counter to the purpose, need, and objectives of the proposed action. Although this concept was

1 not included as an alternative in the DEIS, all LTEMP alternatives include many concepts in this
2 proposal; for example, operations to achieve sediment and native fish objectives are included in
3 several LTEMP alternatives including Alternatives C, D, E, F, and G. Each of these LTEMP
4 alternatives places high priority on protecting existing ecological, physical, and cultural
5 resources and identifies flow and non-flow actions to protect those resources.
6
7

8 **2.3.7 Twelve-Year Experiment of Two Steady-Flow Alternatives**

9

10 Grand Canyon Trust proposed a 12-year series of three 4-year experimental blocks.
11 Operations during the first 4-year period would be seasonally adjusted steady flows. Operations
12 during the next 4-year block would be MLFF. The final 4-year block would feature year-round
13 steady flows. All three flow regimes would include high-flow releases under sediment-enriched
14 conditions. After 12 years, the three regimes would be analyzed to determine which had the most
15 favorable results consistent with the GCPA.
16

17 This alternative was not included in the DEIS, because the proposed experimental design
18 would most likely lead to confounding of effects by the hydrologic patterns that occurred during
19 the LTEMP period, differences in annual volumes, the potential need for equalization operations
20 during one or more years, and differences in sediment supply between treatments. These
21 confounding factors would make it difficult to interpret the results of the proposed experiment.
22 The three operational regimes proposed for this alternative were, however, included as separate
23 alternatives.
24
25

26 **2.3.8 Decommission Glen Canyon Dam Alternative**

27

28 During the public scoping period, several members of the public suggested that an
29 alternative that would result in the decommissioning of Glen Canyon Dam should be considered.
30 Comments suggested that the dam could be either left in place or removed. If left in place,
31 reservoir levels would be equalized to upstream inflows. Lake Powell water levels would drop,
32 and the sediments would begin to cut new banks and form a new channel that would flow around
33 and through the dam. Public comments advocating the decommissioning of the dam mentioned
34 the benefits of opening currently submerged areas to new recreational activities; restoring the
35 environmental, recreational, and cultural resources of the Grand Canyon and the Colorado River
36 basin to their pre-dam conditions; and positively affecting the health of the Colorado River
37 Ecosystem. One commenter suggested transferring the contents of Lake Powell and Lake Mead
38 to underground storage locations to avoid losing water to evaporation. The commenter stated that
39 there are abundant nearby natural underground locations that could accommodate the volume of
40 water from 6 years of the Colorado River's annual flow.
41

42 The Decommission Glen Canyon Dam Alternative was not included in the DEIS because
43 it would not meet the purpose, need, or objectives of the proposed action. The alternative would
44 not allow compliance with water delivery requirements including the Law of the River and 2007
45 Interim Guidelines (Reclamation 2007a,b) and would not comply with other federal requirements
46 and regulations, including the GCPA. This alternative was proposed by members of the public

1 during scoping for the 1995 EIS on Glen Canyon Dam operations, and was not considered for
2 detailed study for reasons similar to those presented above.

3 4 5 **2.3.9 Fill Lake Mead First Alternative**

6
7 The Fill Lake Mead First Alternative was proposed by members of the public during the
8 public scoping comments. Under this alternative, primary water storage would shift from Lake
9 Powell to Lake Mead, using Lake Powell as a backup for seasonal and flood control purposes.
10 According to the commenters, there would likely be less water lost to evaporation and seepage,
11 and there would be greater flexibility for implementing Grand Canyon restoration strategies.
12 This alternative was not included in the DEIS because it would not meet the purpose, need, or
13 objectives of the proposed action. The alternative would not allow compliance with water
14 delivery requirements including the Law of the River and 2007 Interim Guidelines
15 (Reclamation 2007a,b), and would not comply with other federal requirements and regulations,
16 including the GCPA.

17 18 19 **2.3.10 Full-Powerplant Capacity Operations Alternative**

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

30 31 32 **2.3.11 Run-of-the-River Alternative**

33
34 Some members of the public suggested that Glen Canyon Dam could be re-engineered to
35 operate as a modified run-of-the-river facility. A Run-of-the-River Alternative would restore
36 natural water and sediment flows to the greatest extent possible by reconnecting old river bypass
37 tunnels or constructing new tunnels to bypass Glen Canyon Dam. This alternative would utilize
38 elements of the “Fill Lake Mead First” alternative above. This alternative was not included in the
39 DEIS because it would not meet the purpose, need, or objectives of the proposed action. The
40 alternative would not allow compliance with water delivery requirements including the Law of
41 the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other
42 federal requirements and regulations, including the GCPA.

1 **2.4 ALTERNATIVE ELEMENTS ELIMINATED FROM DETAILED STUDY**

2
3 A number of elements were considered by the DOI's LTEMP team for inclusion in
4 LTEMP alternatives, including those identified by the public during the scoping process and
5 alternative workshop in April 2012. Many are included in the alternatives described in
6 Section 2.2. Those eliminated from detailed study are described in this section.
7

8
9 **2.4.1 New Infrastructure**

10
11 Several infrastructure additions and modifications were initially discussed by the DOI
12 during alternative development, including (1) sediment augmentation, (2) a TCD, (3) retrofitting
13 of the bypass tubes to install power generation, and (4) re-engineering of the spillways if needed
14 to allow for more frequent use. Prior to initiation of LTEMP alternative development, options for
15 sediment augmentation, bypass generation, and a TCD were evaluated by Reclamation from
16 engineering assessment and cost perspectives. Several of these options were described in
17 Randle et al. (2006), Reclamation (1999b), and (Vermeyen 2008).
18

19 In addition to infrastructure additions or modifications considered by the DOI, the Basin
20 States and CREDA included several infrastructure considerations in the alternatives they
21 proposed. These are described in the following paragraphs.
22

23 Under Alternative E, the Basin States proposed an investigation to determine the
24 feasibility of using a pump-back system in the Paria River drainage to increase turbidity in the
25 mainstem. This feasibility study would evaluate options, limitations, and cost-benefit. The study
26 would investigate the possibility of installing a pumping system at Lees Ferry to transport a
27 small amount of water up into the Paria River drainage to increase turbidity for a few weeks in
28 the mainstem to disadvantage rainbow trout.
29

30 For Alternative B, CREDA proposed utilizing bubblers in the Glen Canyon forebay to
31 break down the temperature differential between the surface and deeper waters and consequently
32 provide warmer water near the turbine intakes for release downstream. To increase turbidity
33 downstream of the dam, CREDA proposed installing one or more small check dams in the Paria
34 River that would be used to trap sediment for release during a time when young humpback chub
35 are entering the mainstem from the Little Colorado River, thereby enhancing their survival
36 chances by reducing trout predation.
37

38 The DOI considers any infrastructure modifications or additions to be outside the scope
39 of the LTEMP DEIS because they are currently economically infeasible and would require
40 additional congressional authorizations. However, the DOI does not rule out future new
41 infrastructure if resource conditions warrant. Any infrastructure addition or modification would
42 require additional time and study. Future potential infrastructure modifications would need to be
43 evaluated in NEPA assessments (EAs or EISs) that fully considered the environmental impacts
44 of construction and operation. These assessments and the construction of the infrastructure
45 would necessarily result in some delay from the time of the LTEMP ROD and actual start of

1 operation of the infrastructure. It could take as many as 10 years or more to evaluate and
2 construct a TCD or sediment augmentation.

3 4 5 **2.4.2 Flow and Non-Flow Actions** 6

7 A number of flow and non-flow actions were considered by the DOI or proposed by the
8 Cooperating Agencies, stakeholders, or the public for inclusion in the LTEMP DEIS. For various
9 reasons, as described below, these actions were not evaluated in any of the LTEMP alternatives.
10

11 For Alternative E, the Basin States proposed that after every three store-and-release fall
12 HFEs, the next triggered fall HFE would be a “rapid response” HFE in which Glen Canyon Dam
13 releases would be increased within hours or days of a significant input of sediment from the
14 Paria River. Under the alternative, more than one rapid response HFE could occur within a given
15 fall period in response to multiple inputs of sediment. Rapid-response HFEs were not considered
16 in the DEIS because of implementation concerns including the difficulty in coordinating releases
17 with tributary inputs, insufficient lead time to fully notify the public and other stakeholders, and
18 potential safety concerns associated with insufficient notification.
19

20 For Alternative B, CREDA proposed including several experiments that were not
21 included in the alternative as analyzed. These included ponding flows and fluctuating flow
22 experiments. Ponding flows are those relatively high flows that produce low-velocity areas in
23 tributary mouths for the benefit of humpback chub. However, there is little evidence that ponding
24 flows would provide benefit to young of the year humpback chub; therefore, ponding flows were
25 not included as an experimental element in Alternative B or any other alternative. Power
26 production experiments would be short-term flow experiments intended to investigate alternative
27 fluctuating flow parameters that might be compatible with downstream resource objectives.
28 Because specific details of these experiments were not provided by CREDA, they were not
29 included as an experimental element in Alternative B as evaluated in the LTEMP DEIS.
30

31 Some members of the public suggested that the equalization flows identified in the
32 Interim Guidelines (Reclamation 2007a) be released in ways that minimize impacts and provide
33 benefits. Adverse impacts of 2011 equalization flows on sediment resources were mentioned by
34 several commenters. It was suggested that alternatives should consider adjusting timing and
35 magnitude of equalization flows to coincide with available sediment from the Paria and Little
36 Colorado rivers to help rebuild beaches in the Grand Canyon. It was also suggested that
37 equalization flow releases should be implemented over several years rather than in a single year,
38 as currently implemented under the 2007 ROD. This suggested adjustment to an existing recent
39 decision would not meet the purpose, need, or objectives of the LTEMP, which requires
40 compliance with existing, laws, regulations, and decisions.
41

42 Members of the public suggested considering introducing variability in flows by
43 including $\geq 45,000$ -cfs flows. It was suggested that flows of 60,000 cfs and more would be
44 beneficial for sediment-dependent resources in Grand Canyon. This alternative element was not
45 considered for inclusion in alternatives because it would require use of the dam’s spillway,
46 which was designed for occasional use in cases of high inflow and dam safety. The spillway is

1 not engineered for repeated use during normal operations, and any modifications to the dam's
2 infrastructure is considered outside the scope of the DEIS, as discussed in Section 2.4.1. In
3 addition, the spillways can only be used when the reservoir levels are very high; it is not possible
4 to use the spillways at low reservoir elevations. It should be noted that, over the course of the
5 LTEMP period, it is possible that such very high flows would occur as a result of normal
6 hydrologic variation, as happened in the very wet years of 1983 and 1984.

7
8 Mechanical removal of trout in the Glen Canyon reach was considered initially by the
9 DOI during the development of Alternative C. This alternative element was not included in the
10 DEIS because modeling indicated that the effort necessary to effect a reduction in the Glen
11 Canyon trout population with electrofishing would be expensive, impractical, and largely
12 ineffective. TMFs, as included in several LTEMP alternatives, were considered a much more
13 practical way of managing trout population size in the Glen Canyon reach.

14 15 16 **2.5 SUMMARY COMPARISON OF ALTERNATIVES**

17
18 The analysis of alternatives used both quantitative and qualitative approaches. As
19 described in Section 2.1, a structured decision analysis approach was used to develop alternatives
20 and to provide a framework for assessing the performance of alternatives. For this latter function,
21 performance metrics for various resource goals were developed by subject matter experts in
22 Reclamation, NPS, GCMRC, Argonne, FWS, Western, with input from other Cooperating
23 Agencies, AMWG stakeholders, and Tribes (see Appendices B and C).

24
25 For those metrics that could be quantitatively assessed with mathematical models that
26 estimated the response of resources to environmental conditions, a full range of potential
27 hydrologic conditions and sediment conditions were evaluated for a 20-year period (water years
28 2013–2033) that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell
29 inflow scenarios for the 20-year LTEMP were sampled from the 105-yr historic record (water
30 years 1906–2010). This method produced 21 separate hydrology traces (sequence of monthly
31 and annual water volumes) for analysis that represented a range of possible conditions from dry
32 to wet. In addition to these 21 hydrology traces, three 20-year sequences of sediment input from
33 the Paria River sediment record (water years 1964–2013) were analyzed that represented low,
34 medium, and high sediment input. In combination, the 21 hydrology traces and three sediment
35 traces resulted in an analysis that considered 63 possible hydrology-sediment scenarios for
36 analysis.

37
38 Mathematical models were used to predict resource metric values for each of the
39 alternatives under the 63 hydrology-sediment combinations. For resource impacts that could not
40 be modeled, a qualitative approach that relied on observed effects of flows and other factors on
41 resources, as published in the scientific literature, was used to assess impacts. See Chapter 4 for a
42 description of the modeling and assessment approaches used for each resource topic.

43
44 Table 2-14 presents a summary of impacts anticipated under each alternative by resource
45 topic. More detailed information on the impacts of alternatives is provided in Chapter 4.

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

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Water (hydrology and water quality)	No change from current condition	Compared to Alternative A, no change from current condition related to lake elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months. 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 lake elevations, annual operating tiers, monthly release volumes, and mean daily flows; lower mean daily changes in flow in all months; greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A, negligible change from current condition related to lake elevations; no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months; greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A, negligible change from current condition related to lake elevations; no change in annual operating tiers; more even monthly release volumes and mean daily flows; higher mean daily changes in flow in all but Sept. and Oct.; greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to lake elevations and annual operating tiers; large changes in monthly release volumes and mean daily flows; steady flows throughout the year; greatest of all alternatives for summer warming and potential for bacteria and pathogens.	Compared to Alternative A, negligible change from current condition related to lake elevations and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year; greater summer warming and increased potential for bacteria and pathogens.
Sediment	Least HFEs of any alternative would result in highest sand mass balance, lowest potential for building sandbars.	The number of HFEs and bar building potential would be similar to those under Alternative A, but higher fluctuations would result in lower sand mass balance.	High number of HFEs would result in high bar-building potential, but lower sand mass balance than Alternative A.	High number of HFEs would result in high bar-building potential; sand mass balance comparable to Alternative A.	Number of HFEs would result in higher bar-building potential than Alternative A but not other alternatives; lower sand mass balance than Alternative A.	Highest number of HFEs would result in highest bar-building potential, and lowest sand mass balance of all alternatives.	Second highest number of HFEs would result in second highest bar-building potential, and second lowest sand mass balance of all alternatives.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
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.	Similar to Alternative C.	Similar to Alternative B for flow-related processes, but more similar to C for water temperature and sediment-related processes.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within seasonal variability; sediment-related processes similar to Alternative C.	Compared to other alternatives, there would be little variability in flow, water temperature, or water quality processes; Alternative G would have the highest potential of any alternative to build sandbars and retain sand in the system.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic ecology	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows, compared to Alternative A. Habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced compared to Alternative A. Lower trout abundance and slightly higher humpback chub abundance than Alternative A.	Slightly higher productivity of benthic aquatic food base and drift, compared to Alternative A. Habitat quality and stability for nonnative and native fish may be higher than under Alternative A. Higher trout abundance even with implementation of TMFs and mechanical removal, but no difference in humpback chub abundance compared to Alternative A.	Slightly higher productivity of benthic aquatic food base and drift, compared to Alternative A. Experimental steady weekend flows may further increase productivity and diversity. Habitat quality and stability for nonnative and native fish are expected to be slightly higher than under Alternative A. Negligible change in trout abundance with implementation of TMFs, and mechanical removal, and slight increase in humpback chub abundance compared to Alternative A.	Slightly higher productivity of benthic aquatic food base, and similar or increased drift, compared to Alternative A. Habitat quality and stability for nonnative and native fish would be slightly lower than under Alternative A. Lower trout abundance with implementation of TMFs and mechanical removal, and slightly higher humpback chub abundance than Alternative A.	Increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year compared to Alternative A. 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 and slightly lower humpback chub abundance than Alternative A.	Productivity of aquatic food base and long-term drift relatively high compared to Alternative A. Habitat stability for nonnative and native fish would be greater than under any of the other alternatives. Higher trout abundance even with implementation of TMFs and mechanical removal, and slightly lower humpback chub abundance than Alternative A.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Vegetation	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, and increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Similar to Alternative A (decline under hydropower improvement flows). Some adverse impacts and some benefits resulting from narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, increase in arrowweed, increase in native diversity (decrease under hydropower improvement flows), and increase in native/nonnative ratio (decrease under hydropower improvement flows); decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio; decrease in arrowweed; decrease in wetland community cover; impacts on special status species.	Improvement from Alternative A. Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native/nonnative ratio, decrease in arrowweed and increase in native diversity; decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative); decrease in arrowweed; decrease in wetland community cover; impacts and potential benefit to special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio; decrease in arrowweed; decrease in wetland community cover; impacts on special status species.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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 compared to Alternative A; however, hydropower improvement flows would cause a greater decline of wetland habitat.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Increased production of aquatic insects, but accompanying benefits may be offset by higher within-day flow fluctuations.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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 compared to Alternative A.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Cultural resources	No change from current conditions, which may contribute to slumping of terraces in Glen Canyon. HFEs will deposit additional sediment, which will be available for wind transport; however, it is expected that the additional sediment will not significantly improve the stability of archaeological sites in Grand Canyon. No change from current conditions related to the stability of Spencer Steamboat and visitor time off river.	Similar to Alternative A.	Compared to Alternative A, operations could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect to the stability of Spencer Steamboat and time off river.	Compared to Alternative A, extended-duration HFEs could result in additional destabilization of terraces in Glen Canyon but could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect on the stability of Spencer Steamboat and time off river.	No change from current conditions which may contribute to slumping of terraces in Glen Canyon. HFEs will deposit additional sediment which will be available for wind transport; however, it is expected that the additional sediment will not significantly improve the stability of archaeological sites in Grand Canyon. No change from current conditions related to the stability of Spencer Steamboat and visitor time off river.	Similar to Alternative A.	Compared to Alternative A, operations could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect to the stability of Spencer Steamboat and time off river.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	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.	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.	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.	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.	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 plant diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs or mechanical trout removal.	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.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Recreation, visitor use, and experience	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, declining camping area.	Compared to Alternative A, comparable number of HFEs, higher fluctuations, and lowest catch rates; most navigability concerns; declining camping area similar to Alternative A.	Compared to Alternative A, more HFEs, lower fluctuations, similar catch rates; fewer navigation concerns, increasing camping area.	Similar to Alternative C, but with higher daily fluctuations.	Similar to Alternative C, but with higher daily fluctuations.	Compared to Alternative A and all other alternatives, most HFEs, steady flows, higher catch rates, but least large trout; very few navigability concerns, most lost Glen Canyon rafting trips, increasing camping area.	Similar to Alternative F; greatest potential increase in camping area.
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.	Relative 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.	Relative to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, greater disturbance from non-flow actions.	Relative to Alternative A, reversal of camping area decline, similar crowding at rapids, similar level of fluctuations, greater disturbance from non-flow actions.	Relative to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, greater disturbance from non-flow actions.	Relative 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.	Relative to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Visual resources	No change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydropower	No change from current condition. Second highest marketable 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. No change in the value of generation at Hoover Dam.	Compared to Alternative A, 3.8% increase in marketable capacity and 0.02% decrease in total cost to meet electric demand over the 20-year LTEMP period. Small decreases in both the average electric retail rate and the average monthly residential electricity bill in the year of maximum rate impact. No change in the value of generation at Hoover Dam.	Compared to Alternative A, 17.5% decrease in marketable capacity and 0.41% increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 2.0% increase in the value of generation at Hoover Dam.	Compared to Alternative A, 6.7% decrease in marketable capacity and 0.29% increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.0% increase in the value of generation at Hoover Dam.	Compared to Alternative A, 12.2% decrease in marketable capacity and 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.2% increase in the value of generation at Hoover Dam.	Compared to Alternative A, 42.6% decrease in marketable capacity (lowest of alternatives) and 1.2% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period. Highest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 4.1% increase in the value of generation at Hoover Dam.	Compared to Alternative A, 24.2% decrease in marketable capacity and 0.73% increase in total cost to meet electric demand over 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.4% increase in the value of generation at Hoover Dam.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Socioeconomics	No change from current conditions in use values, economic activity or environmental justice with no change in lake levels or river conditions.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation compared to Alternative A. Increases in use values and economic activity associated with Lake Mead recreation. Increased economic activity from lower residential electric bills compared to Alternative A.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper and Lower Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper and Lower Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	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 up to an average of 3.0 years and 0.4 years, 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 up to an average of 6.5 years and 2.8 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 up to an average of 11.0 years and 2.9 years, respectively, of LTEMP period; financial impacts related to electricity sales would be similar to those under Alternative C. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in up to an average of 2.6 years and 1.7 years, respectively, of LTEMP period; financial impacts related to electricity sales would be similar to those under Alternative C. 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 an average of 11.0 years and 3.1 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as \$1.34/MWh) than those on non-Tribal customers, and would be greater (as much as \$2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Air quality	No change from current conditions.	Negligible increase in SO ₂ and NO _x emissions compared to Alternative A.	Negligible decrease in SO ₂ emissions and no change in NO _x emissions compared to Alternative A.	No change in SO ₂ emissions and negligible increase in NO _x emissions compared to Alternative A.	Negligible increase in SO ₂ and NO _x emissions compared to Alternative A.	Negligible decrease in SO ₂ and NO _x emissions compared to Alternative A.	Negligible decrease in SO ₂ and negligible increase in NO _x emissions compared to Alternative A.
Climate change	No change from current conditions.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.
Cumulative impacts	Contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.	Similar to Alternative A, but would have lower trout numbers, slightly higher humpback chub numbers, greater value of hydropower generation and capacity.	Similar to Alternative A, but would have more sandbar building, higher trout numbers, slightly lower humpback chub numbers, lower value of hydropower generation and capacity.	Similar to Alternative A, but would have more sandbar building, higher trout numbers, slightly lower humpback chub numbers, and slightly lower value of hydropower generation and capacity.	Similar to Alternative A, but would have more sandbar building and slightly lower value of hydropower generation and capacity.	Similar to Alternative A, but would have more sandbar building, much higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.	Similar to Alternative A, but would have more sandbar building, higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.

3 AFFECTED ENVIRONMENT

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

3.1 PROJECT AREA

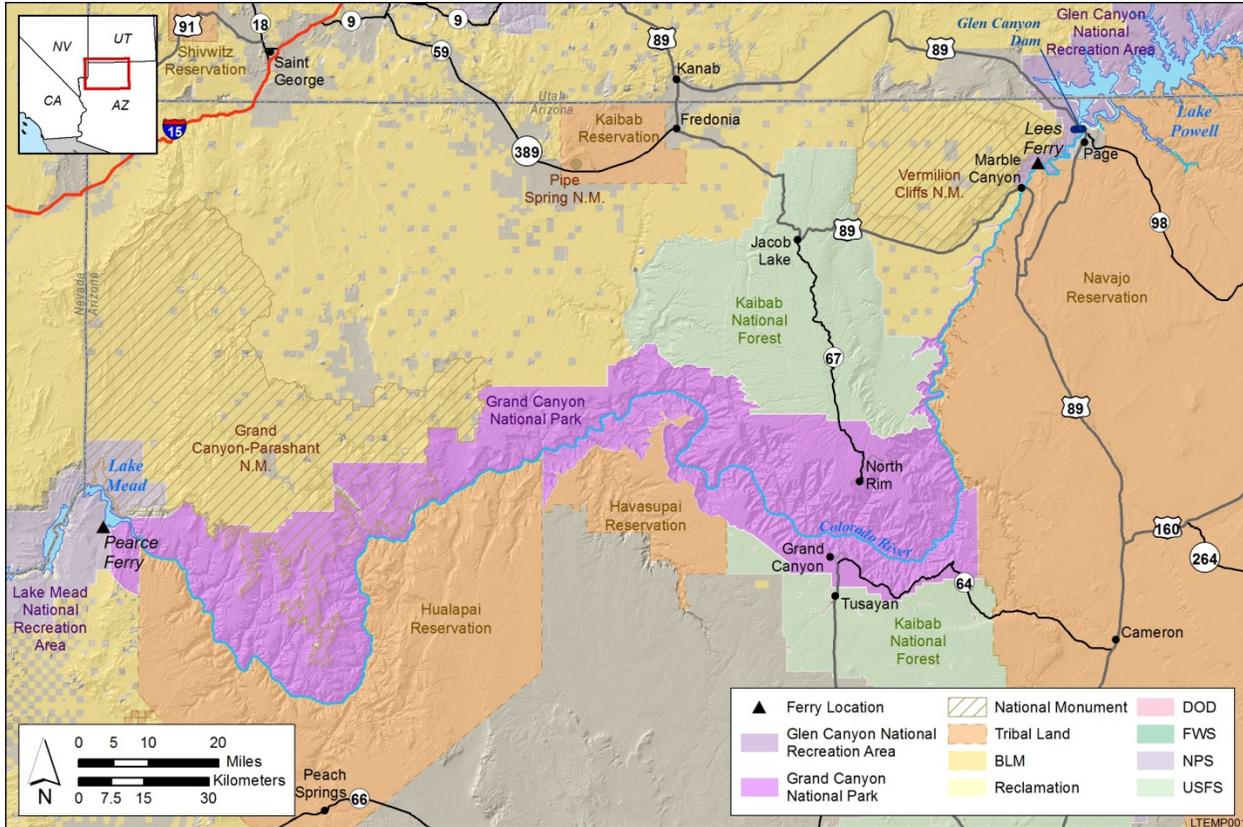
The geographic scope of the LTEMP Draft Environmental Impact Statement (DEIS), as noted in Chapter 1, includes the area potentially directly affected by implementation of the LTEMP (normal and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead. More specifically, the scope primarily includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (GCNP; defined as the Colorado River Ecosystem). It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. Portions of Glen Canyon National Recreation Area (GCNRA), GCNP, and Lake Mead National Recreation Area (LMNRA) are included within this area. For certain resources, such as socioeconomic, air quality, and hydropower, the affected region is larger, and includes areas potentially affected by indirect impacts of the LTEMP. The potentially affected regions for these resources are specifically identified in this chapter and in Chapter 4. Figure 3.1-1 portrays the project area in context with the geographical regions of northern Arizona, southwestern Utah, and southern Nevada.

The following descriptions of geologic setting, climatic setting, and Colorado River linkages for the project area are excerpted from Reclamation (1995).

3.1.1 Geologic Setting

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

In cutting the canyon, the river has exposed rocks of all geologic eras, covering a span of nearly 2 billion years. The rocks of the Grand Canyon are part of the Colorado Plateau, a 130,000-mi² area covering most of the Colorado River Basin. The elevation of the canyon rim



1

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

5

6

7

varies between about 5,000 and 8,000 ft above sea level, with the North Rim being about 1,000 ft
 8 higher than the South Rim.

9

10

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

1 **3.1.2 Climatic Setting**
2

3 Climatic conditions in the area vary considerably with elevation. At Bright Angel
4 Campground (elevation 2,400 ft) near Phantom Ranch, the climate is characterized by mild
5 winters, hot summers, and low rainfall. Average high temperatures range from about 15°C
6 (59°F) in winter to 39°C (103°F) in summer. Low temperatures range from about 4 to 24°C
7 (39 to 76°F). Average annual precipitation, mostly in the form of rain, is about 11.2 in.
8 Precipitation occurs uniformly in summer, fall, and winter and is somewhat less in spring.
9

10 In contrast, the climate at the North Rim (elevation 7,800 to 8,800 ft) is characterized by
11 cold winters, cool summers, and abundant precipitation with snowfall. Average high
12 temperatures range from 4°C (39°F) in winter to 24°C (75°F) in summer; low temperatures range
13 from about -8 to 6°C (18 to 43°F). Average annual precipitation is 33.6 in. The South Rim
14 (elevation 7,000 ft) receives about 16 in. of precipitation annually. Average high temperatures
15 range from 5°C (41°F) in winter to 29°C (84°F) in summer; average low temperatures range
16 from -8°C (18°F) in winter to 12°C (54°F) in summer.
17

18 The Upper Colorado River Basin is generally classified as semiarid and the Lower Basin
19 as arid. The climate varies from cold-humid at the headwaters in the high mountains of
20 Colorado, New Mexico, Utah, and Wyoming to dry-temperate in the northern areas below the
21 mountains and arid in the lower southern areas. Annual precipitation in the higher mountains
22 occurs mostly as snow, which results in as much as 60 in. of precipitation per year. Thousands of
23 square miles in the lower part of the basin are sparsely vegetated because of low rainfall and
24 poor soil conditions. Rainfall in this area averages from 6 to 8 in., mostly from cloudburst storms
25 during the late summer and early fall.
26
27

28 **3.1.3 Colorado River Ecosystem Resource Linkages**
29

30 Resources downstream from Glen Canyon Dam through the Grand Canyon are
31 interrelated, or linked, since virtually all of them are associated with or dependent on water and
32 sediment. This section gives an overview of linkages within this Colorado River Ecosystem to
33 better illustrate the interdependence of processes and resources in the study area. A detailed
34 description of resources follows this overview.
35

36 The Colorado River Ecosystem is the system of concern in this DEIS; it includes
37 resources located in the river channel and in a relatively narrow band of adjacent land. Resources
38 within this system depend on factors outside these operationally defined boundaries, including
39 the physical and biological constraints of Lake Powell and, to a lesser extent, Lake Mead and
40 tributaries such as the Little Colorado River.
41

42 The Colorado River Ecosystem originally developed in a sediment-laden, seasonally
43 flooded environment. The construction of Glen Canyon Dam altered the natural dynamics of the
44 Colorado River. Today, the ecological resources of the Grand Canyon depend on the water
45 releases from the dam and variable sediment inputs from tributaries.
46

1 Lake Powell traps water, sediment, and associated nutrients that previously traveled
2 down the Colorado River. Interruption of river flow and regulated release of lake water now
3 results in altered aquatic and terrestrial systems compared to those before Glen Canyon Dam.
4 Sections 3.2 through 3.16 discuss the current status of resources of the Colorado River
5 Ecosystem and how dam operations affect them either directly or through linkages among
6 resources. The present interactions among water volume and release patterns, sediment transport,
7 and downstream resources have created and support a complex system much different from pre-
8 dam conditions.

11 3.1.3.1 Water Release Characteristics

13 The major function of Glen Canyon Dam (and Lake Powell) is water storage. In this
14 DEIS, river flows below the dam are referred to as releases or flows. River flow is measured in
15 cubic feet per second (cfs). Annual and monthly volumes are measured in acre-feet. The amount
16 of water and its pattern of release directly or indirectly affect physical, biological, cultural, and
17 recreational resources within the river corridor.

19 Pre-dam flows ranged seasonally from spring peaks sometimes greater than 100,000 cfs
20 to winter lows of 1,000 to 3,000 cfs. During spring snowmelt periods and flash floods,
21 significant daily and hourly flow fluctuations often occurred. While annual variability in water
22 volume was high, a generally consistent pattern of high spring flows followed by lower summer
23 flows provided an important environmental factor for plants and animals in the river and along
24 its shoreline.

26 Post-dam water releases fluctuate on a daily and hourly basis to maximize the value of
27 generated power by providing peaking power during high-demand periods. More power is
28 produced by releasing more water through the dam's generators. Daily releases can range from
29 5,000 to 31,500 cfs, but actual daily fluctuations have been less than this maximum range since
30 implementation of the 1996 Record of Decision (Reclamation 1996). These fluctuations result in
31 a downstream "fluctuation zone" between low and high river stages (water level associated with
32 a given flow) that is inundated and exposed on a daily basis. For purposes of this analysis, flows
33 are defined as fluctuating if they both increase and decrease more than 2,000 cfs in a 24-hour
34 period.

36 Hydropower is cleaner than nonrenewable fuel resources, and if water releases are less
37 constrained, hydropower can be more responsive to changes in load than many other forms of
38 electrical generation. The Glen Canyon Powerplant is an important component of the electrical
39 power system of the western United States. The powerplant has eight generating units with a
40 maximum combined capacity (i.e., the maximum electric output of the eight generating units) of
41 1,320 MW. When operating policies allow, releases are scheduled to be higher during months
42 when power demand is greatest, typically during the summer and winter.

44 Glen Canyon Dam also affects downstream water temperature and clarity. Historically,
45 the Colorado River and its larger tributaries were characterized by heavy sediment loads,
46 variable water temperatures, large seasonal flow fluctuations, extreme turbulence, and a wide

1 range of dissolved solids concentrations. The dam has altered these characteristics. Before the
2 dam, water temperature varied on a seasonal basis from highs around 27°C (80°F) to lows near
3 freezing. Now, water released from Glen Canyon Dam averages 8°C (46°F) year round, although
4 releases temperatures vary depending on the water level in Lake Powell and other factors, and
5 water temperature warms by about 1°C (1.8°F) for every 30 mi traveled downstream during
6 warmer months of the year (Reclamation 1999b). Lake Powell traps sediment that historically
7 was transported downstream. The dam releases clear water, and the river becomes muddy when
8 downstream tributaries contribute sediment, as during summer monsoon storms.

11 **3.2 WATER RESOURCES**

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

18
19 The hydrology of the Colorado River, as discussed in this EIS, refers to the water
20 volumes, flow rates, and open channel hydraulics (i.e., characteristics of the conveyed flow such
21 as depths and velocities) of the lakes, the river, and its tributaries. These aspects of Colorado
22 River hydrology are directly affected by the proposed action of changes in operations at Glen
23 Canyon Dam. Hydrology directly affects water quality variables in the downstream river
24 environment such as temperature, salinity, and turbidity. Sediment transport and channel and
25 floodplain morphology (e.g., pools, rapids, sand bars, and terraces) are controlled and shaped by
26 the river's hydrologic properties. From a habitat perspective, these attributes form the basis for
27 aquatic organisms to live and supply food for subsistence and growth. They also generate flow
28 regimes and physical environments that greatly influence the terrestrial plant and animal
29 communities living along the banks of the river. Members of American Indian Tribes, including
30 the Hualapai, Havasupai, Hopi, Kaibab Band of the Paiute, Navajo, and Zuni, depend upon the
31 river and its waters for economic, historical, and cultural values. From a recreation standpoint,
32 water-based and water-related activities rely heavily on the hydrology of both the river and its
33 reservoirs. Finally, hydropower and water delivery (in accordance with legal obligations outlined
34 in the Law of the River; refer to Section 1.6.2 for further details) are dependent on the Colorado
35 River Basin hydrology.

38 **3.2.1 Hydrology**

39
40 The primary source for the total annual water flow in the basin is mountain snowmelt.
41 Therefore, unregulated river flows are typically very high in the late spring and early summer
42 and diminish rapidly by midsummer, although flows in late summer through autumn sometimes
43 increase following monsoonal rain events (Reclamation 2007a). In general, the average annual
44 natural flow of the Colorado River at Lees Ferry over the 105-year period (water years 1906
45 through 2010) has averaged around 15 million acre-feet (maf), but has ranged between
46 approximately 5.4 and 25.4 maf (Reclamation 2007a, 2013a). The period from water years 2000

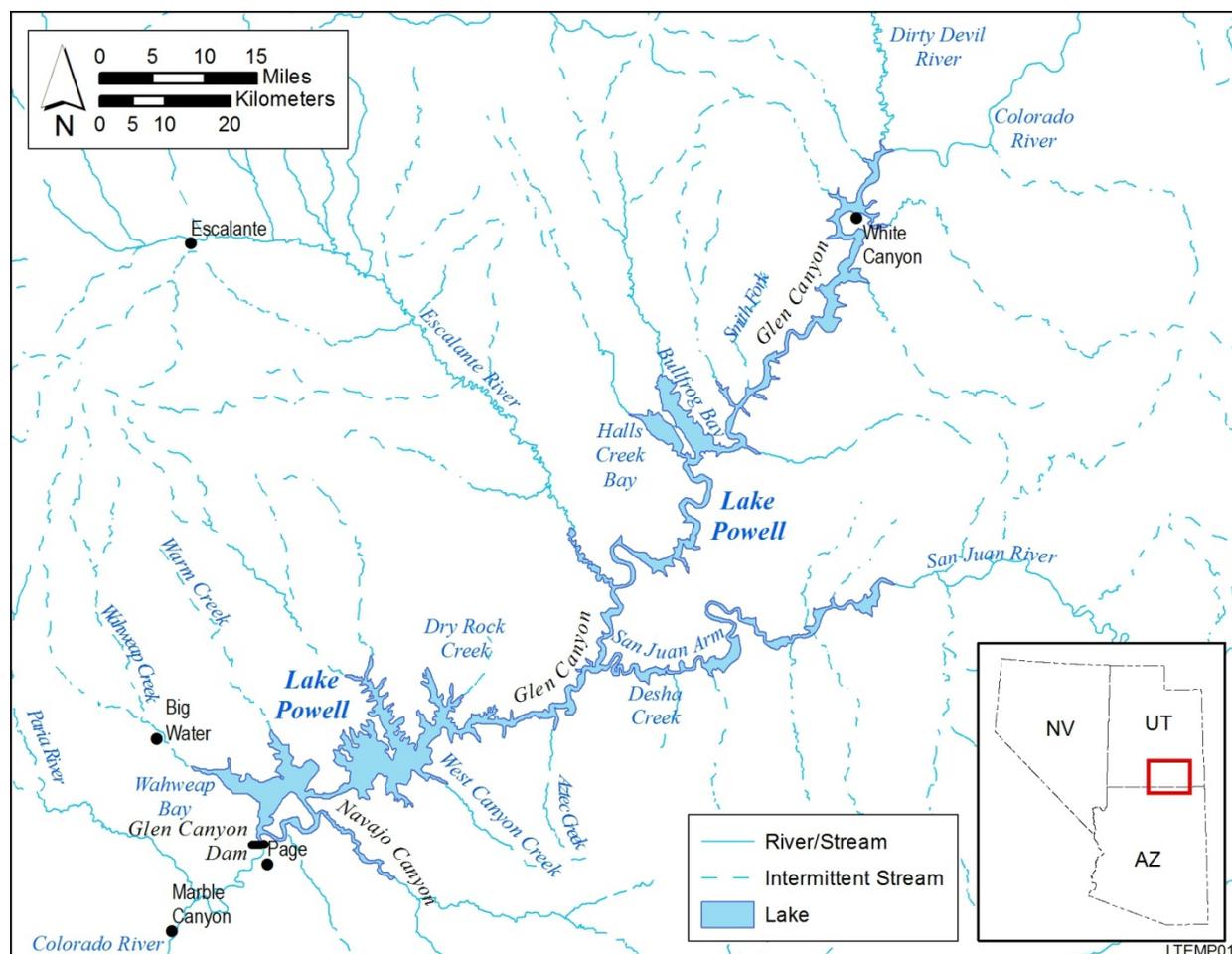
1 to 2010 was the driest 11-year period in the more than 100-year historical record for the
2 Colorado River Basin (average annual flow of 12.1 maf); the period from water years 1999 to
3 2010 was the second-driest 12-year period (12.5 maf) on record (Holdren et al. 2012; GCMRC
4 2015a). Based on historical (1922–2015) Lees Ferry flow data from GCMRC (2015a), the most
5 recent 10-year period (2006–2015) was drier than 77% of all 10-year periods since 1922, and the
6 most recent 20-year period (1996–2015) was drier than 73% of all 20-year periods since 1922.
7 These two periods had average annual cumulative flows of 9.0 maf and 9.6maf, respectively.
8 Average annual natural flow is forecast to decline in the future (Seager et al. 2007;
9 Vano et al. 2013; Reclamation 2012e).

12 **3.2.1.1 Lake Powell Hydrology**

13
14 Lake Powell, illustrated in Figure 3.2-1, along with its associated major tributaries, is the
15 second-largest man-made reservoir on the Colorado River (Lake Mead is the largest), with a
16 maximum water storage capacity of around 24.3 maf. At full pool capacity the mean depth is
17 approximately 165 ft, with a maximum depth of about 560 ft in the forebay area of the dam.
18 Lake Powell provides water storage for use in meeting the delivery requirements to the Lower
19 Basin consistent with the Law of the River (Reclamation 2007a). Its waters are also used for
20 recreation and generation of hydroelectric power through the Glen Canyon Dam powerplant, as
21 well as a municipal water source for the City of Page, Navajo Community, Chapter of LeChee
22 and industrial water for the Navajo Generating Station.

23
24 The reservoir is long and narrow, more than 180 mi long and often less than a mile wide.
25 The water level of Lake Powell is designed to operate the dam between elevations of 3,490 and
26 3,700 ft above mean sea level (AMSL). As the water level changes, the surface of Lake Powell
27 varies in size from about 52,000 to 163,000 ac, and the shoreline fluctuates from approximately
28 990 to 1,960 mi long; it is fully encompassed by the GCNRA (NPS 2003). At the full pool
29 elevation of Lake Powell, this reach includes approximately 25 mi of Cataract Canyon, more
30 than 50 mi of the San Juan River, and approximately 170 mi of Glen Canyon
31 (Reclamation 1995, 2007a). Almost half of the reservoir’s capacity lies in its upper 100 ft, a zone
32 where the lake overtops many local plateau surfaces. The floor of the reservoir is the incised bed
33 of the former Colorado River, ranging from around 500 to 800 ft in width at its bottom, with a
34 nearly uniform grade of 0.038% (Johnson and Merritt 1979). Lake Powell contains more than
35 90 major side canyons that have unique orientations and morphologies owing to differences in
36 size, orientation, inflow contributions (springs and tributary flows), mixing processes, and visitor
37 activities; however, it appears that side canyon portions of the reservoir generally have the same
38 chemical and physical stratification as that of the main lake body (Taylor et al. 2004).

39
40 The hydrology of Lake Powell is primarily influenced by basin-wide hydrology and
41 subsequently annual inflow into the lake. Dam operations affect the hydrology of Lake Powell,
42 but to a much lesser extent. In addition, the elevation of Lake Powell and the timing, volume,
43 and water quality of inflow into Lake Powell influence the water quality of releases from Glen
44 Canyon Dam, which has subsequent effects on the downstream water quality of the Colorado
45 River in Glen and Grand Canyons. The proposed action would not affect annual inflow patterns.



1

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

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One of the most important factors driving short-term and long-term processes in Lake Powell is the inflow hydrology, characterized by the volume and quality of inflows to the reservoir and their seasonal variation (Vernieu and Hueftle 1998). Overall, approximately 95% of the reservoir’s inflow originates from the mainstream of the Colorado River and two major tributaries, the San Juan and Green Rivers (Stanford and Ward 1991; Reclamation 1995, 2007a; Wildman et al. 2011). Specifically, since water year 2005, the Upper Colorado River Basin has experienced significant year-to-year hydrologic variability. The unregulated inflow (i.e., the inflow that would occur if no upstream reservoirs existed) to Lake Powell has averaged a water year volume of 10.22 maf (94% of 30-year average for the 1981–2010 period) during the period from 2005 through 2012. The hydrologic variability during this same period (from 2005 to 2012) resulted from a low water year unregulated inflow volume of 4.91 maf (45% of the 30-year average) in water year 2012 and a high water year unregulated inflow volume of 15.97 maf (147% of the 30-year average) in water year 2011 (Reclamation 2013c).

The majority of the inflow into Lake Powell, around 60%, occurs in late spring and early summer as a result of snowmelt in the Rocky Mountains and Upper Colorado River Basin

1 (Iorns et al. 1965; Evans and Paulson 1983; Vernieu et al. 2005). This runoff tends to be warm,
2 low in salinity, and turbid (i.e., sediment laden) as a result of its passage through the canyonlands
3 and, because of its temperature, it represents the lowest-density water entering the reservoir
4 during the year. Consequently, this water travels along the top of the reservoir as an overflow
5 density current, leaving the waters below the penstock level (i.e., elevation 3,470 ft) essentially
6 untouched (Johnson and Merritt 1979; Vernieu and Hueftle 1998; Vernieu et al. 2005;
7 Reclamation 1995).

8
9 Winter inflows are cold and saline and represent the highest-density inflows to the
10 reservoir during the year. Depending on the relative density of the existing hypolimnion in
11 Lake Powell, winter inflows may flow along the bottom of the reservoir as an underflow-density
12 current (Johnson and Merritt 1979), routing fresh water to the hypolimnion and displacing older
13 oxygen-poor saline water upward toward the dam release structures. During the spring of each
14 year from 1999 to 2008, winter inflows moving through Lake Powell had sufficient density to
15 flow along the bottom of the reservoir (Vernieu 2010). If winter inflows are less dense than the
16 water in the hypolimnion, as might happen following years of low runoff that establish saline
17 conditions, they will flow into intermediate layers as an interflow-density current, eventually
18 being discharged through the penstock outlet and leaving deeper waters stagnant (Vernieu and
19 Hueftle 1998; Reclamation 1995; Vernieu et al. 2005). This condition was observed at
20 Lake Powell from 1991 to 1998 (Vernieu 2010). Regardless of whether the winter inflow density
21 current overrides or displaces the hypolimnion, there is a consistent annual pattern of colder and
22 more saline water around the penstock withdrawal zone during the winter months.

23
24 Early dam operations focused on filling Lake Powell, delivering water to Lake Mead, and
25 producing hydropower. Operations during the relatively full period from 1980 to 1987 focused
26 primarily on water delivery and power generation, although managing spring inflows and
27 protecting the integrity of the dam were also important. Since the early 1990s, operations have
28 continued to focus on meeting water allocation requirements and producing power, but they
29 changed to comply with operational criteria (e.g., minimum and maximum limits on discharge
30 and ramping rates) and environmental constraints designed to minimize the effects of Glen
31 Canyon Dam on downstream resources (Reclamation 1995). This period is also marked by
32 numerous experimental flows and manipulations to the operation of Glen Canyon Dam for
33 scientific and environmental purposes. In addition, the Upper Colorado River Basin has
34 experienced significant hydrologic variability during the period since 1991. For example, as a
35 result of the summer monsoon of 1999, the late summer inflow to Lake Powell was unusually
36 high at 196% and 176% of average in August and September, respectively, which led to nearly
37 full reservoir levels though the end of water year 1999 (DOI 2002). However, drought conditions
38 during the 2000s led to around 50–60% below-average inflows to Lake Powell, with the inflow
39 in water year 2002 being the lowest observed since the completion of Glen Canyon Dam in 1963
40 (DOI 2002). By 2005, water storage was reduced by approximately 60% to the lowest level since
41 1969 (Vernieu 2009; Vernieu et al. 2005). Changing hydrological conditions have had varying
42 effects on the chemical and physical stratification of Lake Powell (as described in more detail in
43 the following sections), depending on the storage conditions, inflows, and prescribed release
44 regime.

1 **3.2.1.2 Hydrology of the Colorado River Downstream of Glen Canyon Dam**
2

3 Annual water volumes are established pursuant to the adopted Interim Guidelines for
4 Coordinated Operations of Lake Powell and Lake Mead (Reclamation 2007a). The interim
5 guidelines for coordinated operations of Lake Powell and Lake Mead define four operation tiers:
6 (1) the Equalization Tier, (2) the Upper Elevation Balancing Tier, (3) the Mid-elevation Tier, and
7 (4) the Lower Elevation Balancing Tier. Releases greater than 9.5 maf would occur during the
8 Equalization Tier. Annual releases of 7.48 maf occur in the Mid-elevation Tier. Annual releases
9 between 7.48 and 9.5 maf generally occur in the two balancing tiers. Implementation of
10 equalization and balancing follow descriptions in the Interim Guidelines for Lower Basin
11 Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).
12 Notably, when operating in the Equalization Tier, the Upper Elevation Balancing Tier, or the
13 Lower Elevation Balancing Tier, scheduled water year releases from Lake Powell would be
14 adjusted each month based on forecast inflow and projected September 30 live storage at Lakes
15 Powell and Mead.
16

17 The annual releases since the dam was completed have included relatively high annual
18 volumes (above 8.23 maf) numerous times. In general, each period of higher release was
19 followed by a reduction in the salinity of the hypolimnion, the lower layer of water in a stratified
20 lake (Vernieu and Hueftle 1998). Monthly release volumes are based on anticipated power
21 demands, forecasted inflows, and other factors such as storage equalization between Lake Powell
22 and Lake Mead. High release volumes do not always coincide with peaks in reservoir inflow;
23 instead, they coincide with times of increased power demands (e.g., January and August).
24 Therefore, the timing of these high releases may or may not facilitate the drawing and
25 replacement of hypolimnetic waters near the dam (Vernieu and Hueftle 1998).
26

27 The Lees Ferry gaging station (river mile [RM] 0), which has been operated by the
28 U.S. Geological Survey (USGS) since May 1921, is approximately 15.5 mi downstream from the
29 Glen Canyon Dam and approximately 1 mi upstream of the Paria River mouth. Its location
30 allows a comparison of pre-dam flows with post-dam flows downstream of Glen Canyon Dam,
31 because it is located close to the dam but is unaffected by the presence of tributary inflows.
32 Historically, the Lees Ferry gage station data has been subject to the most rigorous scientific
33 collection and analysis. Therefore, this section primarily utilizes the Lees Ferry data and
34 analysis. Figure 3.2-2 illustrates the changes in the pattern of annual flows at Lees Ferry for the
35 pre-dam period (from 1922, when continuous records began, through 1962) and post-dam period
36 (1963 through 1989) (Reclamation 1995).
37

38 The average pre-dam peak annual discharge was found to be approximately 92,000 cfs
39 (Topping et al. 2003). The largest peak flow during the pre-dam period (data record from 1921 to
40 1963) occurred in June 1921, soon after the installation of the Lees Ferry gage. This flood was
41 estimated to have a peak flow of 170,000 ± 20,000 cfs; the return period of this event was
42 estimated to be 40 years (Topping et al. 2003; O'Connor et al. 1994). The average 2-year
43 recurrence interval flood peak was calculated from the discharge record to be 85,000 cfs
44 (Topping et al. 2003).
45

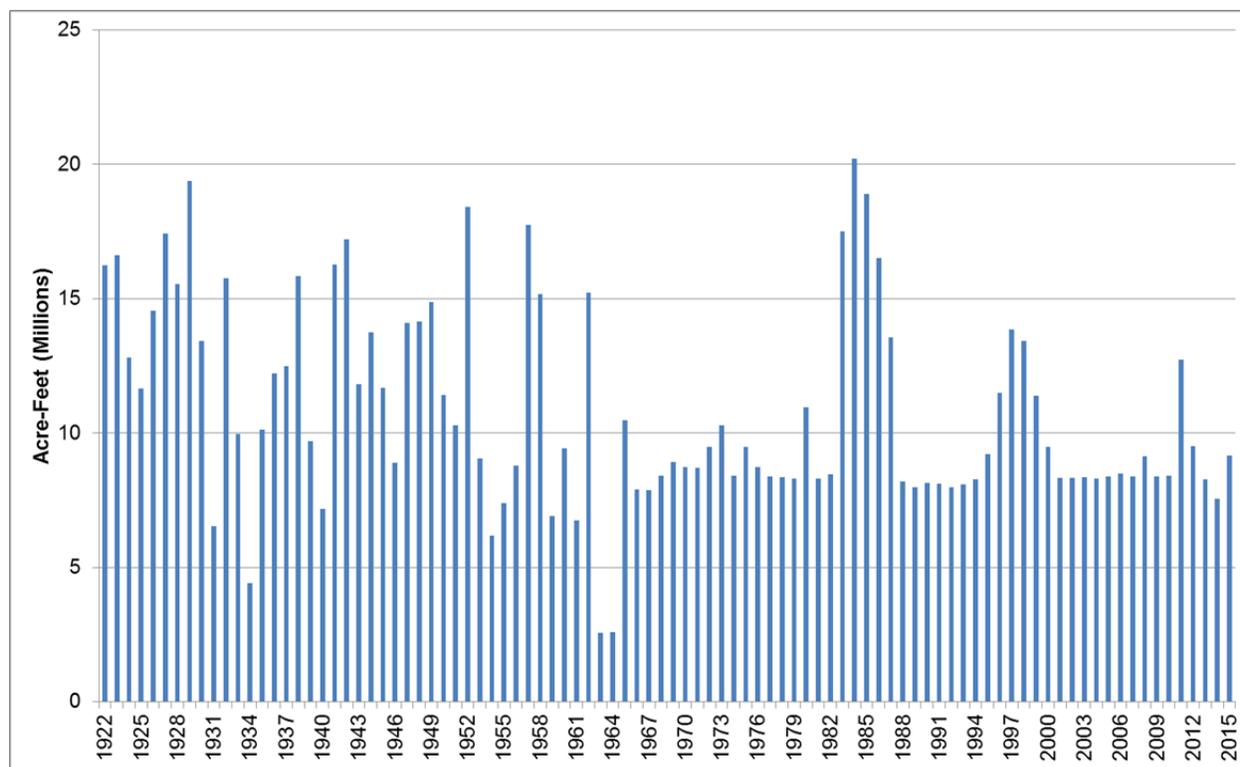


FIGURE 3.2-2 The Pattern of Annual Historic Flows at Lees Ferry (Source: GCMRC 2015a)

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

Periodic releases of relatively short duration that bypass the hydropower plant have also occurred at the Glen Canyon Dam. Examples of releases that have utilized these structures include 1965–1966 releases for filling Lake Mead; mid-1980s flood years; and HFEs conducted in 1996, 2004, 2008, 2012, and 2013.

3.2.1.3 Lake Mead Hydrology

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

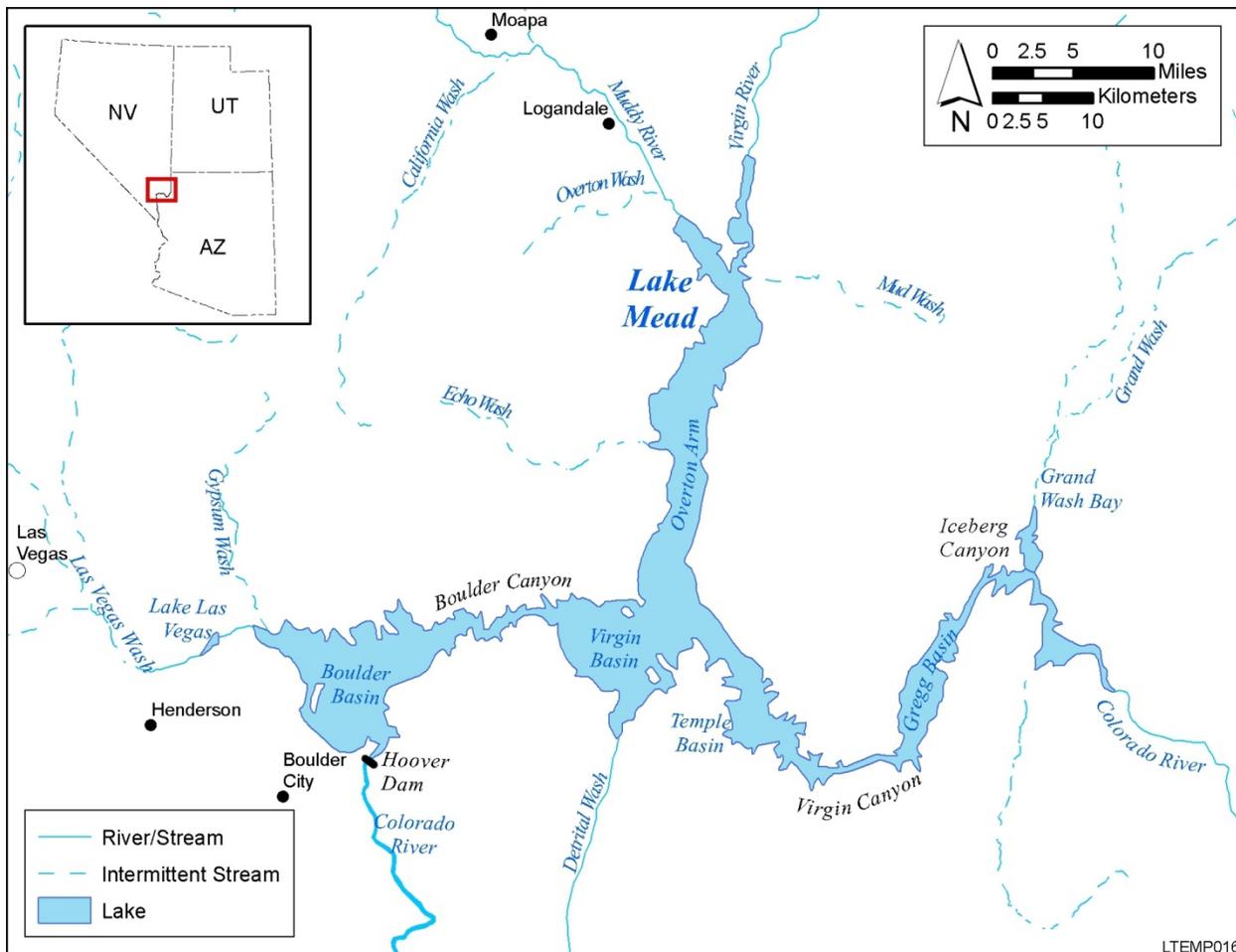


FIGURE 3.2-3 Map of Lake Mead and Associated Major Tributaries

1 Lake Mead is a large, deep-storage reservoir with a maximum depth of approximately
2 490 ft and a mean depth of nearly 170 ft. It is approximately 110 mi long, extending from the
3 mouth of the Grand Canyon at Pearce Ferry to Hoover Dam in Black Canyon. With a width that
4 varies from several hundred feet in the canyons to more than 9 mi, Lake Mead has the largest
5 surface area of any reservoir in the Northern Hemisphere, covering about 160,000 ac (250 mi²)
6 with a shoreline that is more than 550 mi long (Reclamation 2012a; Turner et al. 2011; Evans
7 and Paulson 1983). The hydraulic residence time of Lake Mead depends upon reservoir release
8 and inflow patterns (which are dependent upon Glen Canyon Dam releases). Estimates have
9 calculated residence times on the order of about 2.6 years, based on average inflows and lake
10 volumes (Turner et al. 2012; Holdren 2012). When the reservoir is thermally stratified, the
11 surface layer (the epilimnion) occurs from approximately 0 to 65 ft, the metalimnion occurs from
12 approximately 65 to 100 ft, and the deep hypolimnion occurs from approximately 100 ft to the
13 bottom of the reservoir.

14
15 Lake Mead can be divided along the historical Colorado River channel into four large
16 sub-basins: Boulder, Virgin, Temple, and Gregg; four narrow canyons: Black, Boulder, Virgin,
17 and Iceberg; and the 30-mi-long Overton Arm, which extends from the Virgin and Muddy Rivers
18 to the Virgin Basin (Figure 3.2-3). The Colorado River enters the eastern end of Lake Mead at
19 the upper end of Gregg Basin at current (2011) lake levels.

20
21 Historically, Colorado River inflow into Lake Mead was unregulated and reflected
22 natural hydrologic variability; volumes depended upon the annual snowmelt and rainfall received
23 on the west side of the Rocky Mountains in Colorado. Regulation of inflow began in 1963, when
24 Glen Canyon Dam was constructed approximately 280 mi upstream. The formation of
25 Lake Powell and operation of Glen Canyon Dam have altered the physical characteristics of the
26 Colorado River inflow to Lake Mead. In general, total annual inflows to Lake Mead averaged
27 about 10.9 maf between 1935 and 2001 (Ferrari 2008). Flows decreased from 1999 through 2010
28 as the entire Colorado River Basin experienced drought conditions. More recent (1999–2010)
29 Colorado River annual inflows have averaged 8.23 maf, with additional inflow of approximately
30 0.7 maf contributed by the lake's other tributaries, thus providing a total average operational
31 inflow into Lake Mead of 9.0 maf (Holdren et al. 2012; Turner et al. 2012).

32 33 34 **3.2.1.4 Seeps and Springs**

35
36 Although the Colorado River flows through the Grand Canyon, its waters do not originate
37 there. The Grand Canyon's only native waters (i.e., waters derived in place) come from the more
38 than 1,000 springs and seeps that are recharged by precipitation on the high plateaus surrounding
39 the canyon (i.e., Coconino on the South Rim and Kaibab on the North Rim) and discharged
40 along the walls below the rim. Some springs, such as Pumpkin Spring and Fence Spring, are
41 within the area of the river corridor potentially affected by the proposed action.

42
43 Although springs make up less than 0.01% of the Grand Canyon's landscape, they are
44 ecologically important (Rice 2013). Each spring is unique and supports a distinctive array of
45 flora and fauna, many of which are endangered and endemic (i.e., found nowhere else). It has
46 been estimated that species diversity is 100 to 500 times greater in the vicinity of the springs than

1 the surrounding areas (NPS 2014a). Any changes or declines in flow of a small spring or seep
2 may change a perennial system into an intermittent one, or dry the system out completely. Thus,
3 species such as riparian plants, fish, amphibians, and invertebrates that rely on these water
4 sources may be lost because they do not often have a mechanism to move across the desert
5 landscape to a new water source (Rice 2013).
6

7 Many springs and seeps also hold cultural significance for Native Americans in the
8 region. For example, from the Zuni perspective, the earth is circular in shape and is surrounded
9 on all sides by ocean. Under the earth is a system of covered waterways, all ultimately
10 connecting with the surrounding oceans, springs, and lakes, which are the openings to this
11 system (Bunzel 1932) and are regarded as sacred to the Zuni because they provide water, a life-
12 giving substance that is necessary to maintain life within the Southwest's harsh environment.
13 Springs are specifically "considered to be the most precious things on Earth" (Hart 1980). The
14 Grand Canyon contains numerous springs that are utilized among all religious groups for
15 traditional and religious practices and play an integral role in water collecting by the Zuni people
16 for ceremonial use.
17

18 The Hualapai consider *Ha'thi-el* (Salty Spring), a sacred spring within the Canyon, to
19 contain a petroglyph site that tells of the creation of the Hualapai and other Pai peoples
20 (HDCR 2010). Other springs, such as Pumpkin Spring at RM 213 and Medicine Spring at the
21 downstream end of Lava Falls Rapid, are warm mineral springs and are considered to have
22 healing properties. Pumpkin Spring is immediately above the level of typical operational flows,
23 although in the pre-dam past it would have regularly been inundated and flushed during the
24 frequent flood episodes. As it stands now, it rarely is subject to inundation, and algae, toxic
25 bacteria, and concentrated minerals have rendered the spring a potential health hazard.
26

27 All springs in the canyons have a spiritual importance to Hopi; water in general is a
28 central feature in all of Hopi philosophy, and springs in particular are considered to be altars
29 (Hough 1906). Water is collected at a number of springs in the canyons for ceremonial use by
30 Hopi, and prayers are offered to all of the spring locations. The Sipapuni, the origin location for
31 the Hopi people, is a spring. Springs provide habitat for culturally important plants and animals
32 that are rare in the otherwise arid region. Finally, springs have a key historical importance as
33 water sources for the Hopi ancestors who resided in the canyons.
34

35 The Havasupai are dependent on the springs that emit from the shallow and deep aquifers
36 on their reservation and in GCNP. The spring water that flows through the Village of Supai and
37 over the spectacular waterfalls on the reservation delivers approximately 49,000 ac-ft per year to
38 the Colorado River. The Havasupai consider all springs to be sacred, with some having particular
39 significance in tribal religious and cultural practices. They have also historically farmed at the
40 major springs, including what is now called Indian Gardens in GCNP (Hirst 1985).
41
42

1 **3.2.2 Water Quality**
2
3

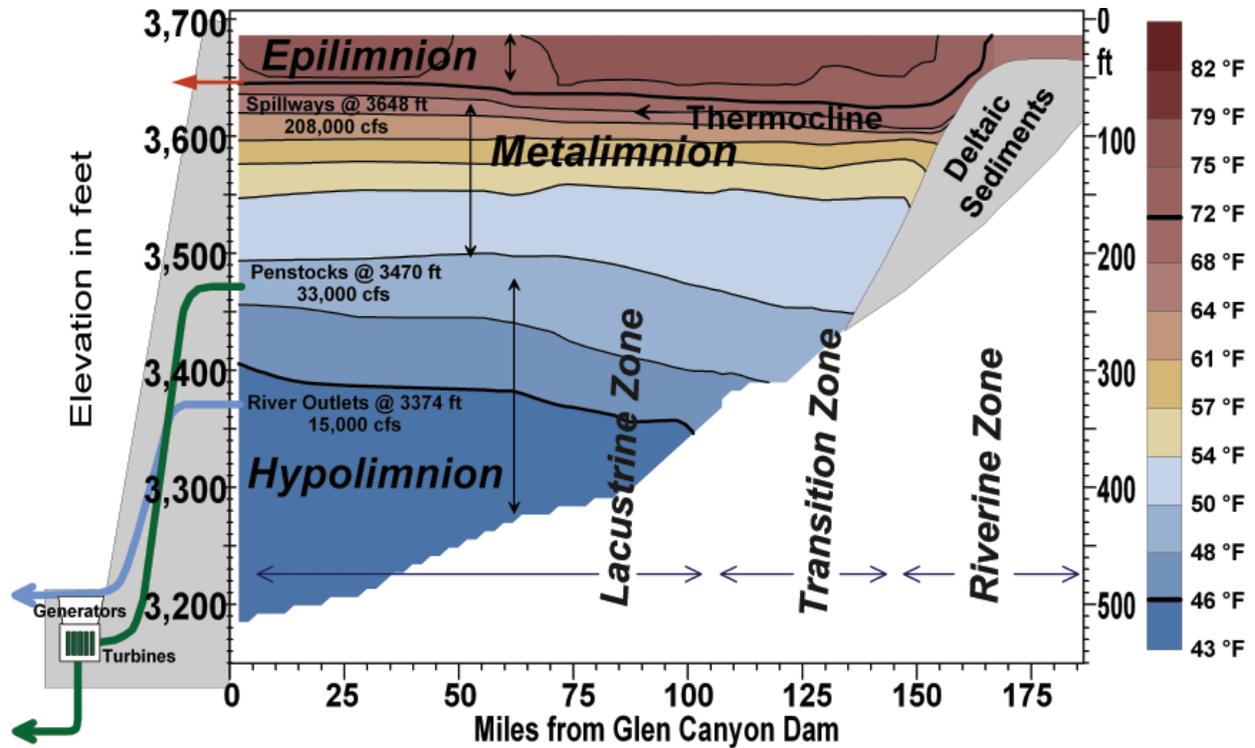
4 **3.2.2.1 Lake Powell Water Quality**
5

6 The stratification of Lake Powell influences many chemical and biological processes in
7 the lake and, as a result, influences the characteristics and quality of water that is released to the
8 Colorado River below the dam (Hart and Sherman 1996). As described previously, Lake Powell
9 is thermally and chemically stratified into density layers that differ vertically and longitudinally.
10 In general, vertical stratification varies seasonally and is determined by the relative density of
11 different layers of the reservoir; longitudinal variation in water quality is the result of currents
12 moving through the reservoir (Vernieu et al. 2005). The physical, chemical, and biological
13 characteristics of Lake Powell have a direct effect on the quality of water drawn from and
14 released below Glen Canyon Dam.
15

16 Lake Powell is thermally stratified through much of the spring, summer, and early fall
17 (typically April–October) (Figure 3.2-4). In general, the epilimnion of Lake Powell, which
18 ranges from the lake surface to a depth of about 60 ft, depending on season and location (Hart
19 and Sherman 1996; Vernieu et al. 2005), exhibits the highest temperatures within the reservoir
20 and varies little with depth. Warmed by spring inflows, ambient air temperature, and solar
21 radiation, summer temperatures can reach around 25–30°C (77–86°F), while winter temperatures
22 may drop to 6–10°C (45–50°F) (Stanford and Ward 1991; Vernieu et al. 2005;
23 Reclamation 1995, 1999b). The metalimnion typically ranges from 60 to 180 ft in depth and
24 exhibits decreasing water temperatures with depth because sunlight’s ability to warm water also
25 decreases with depth (Hart and Sherman 1996; Reclamation 1995). The hypolimnion, which
26 begins around 180 ft below the surface of the reservoir, is typically too deep for sunlight to
27 reach, and water temperatures are lower and remain nearly constant at about 6–9°C (43–48°F)
28 (Vernieu et al. 2005; Hart and Sherman 1996; Reclamation 1995).
29

30 During the winter period (November–March), the thermal stratification breaks down as
31 cooling surface waters are mixed with deeper water by the wind and vertical currents. By the end
32 of the calendar year, mixing typically progresses to the depth of the penstock withdrawals. At
33 this point, the release waters begin to exhibit characteristics of the epilimnion, which contains the
34 warmest water in the reservoir at that time of year, despite the cooler weather conditions
35 (Vernieu et al. 2005). Thus, the warmest release temperatures of the year occur in late fall to
36 early winter, then temperatures begin to cool again as vertical currents mix the lake down to the
37 penstocks depth, which occurs before thermal stratification begins to reestablish.
38

39 During the ongoing drought in the 2000s, Lake Powell levels generally declined and
40 release temperatures gradually begun to warm (Vernieu et al. 2005). Since then, total Colorado
41 Basin storage has experienced year-to-year fluctuations in response to wet and dry hydrology,
42 but water temperatures have continued on a general warming trend compared to the early 1990s
43 (refer to Section 3.2.2.3 for further details on Colorado River water temperature). Figure 3.2-5
44 presents the water temperatures measured at Lees Ferry (the official point of measurement for
45 water deliveries to the lower basin states) from 1991–2013, illustrating the aforementioned
46 warming of the Glen Canyon Dam releases. Note that in water year 2011, there was a record

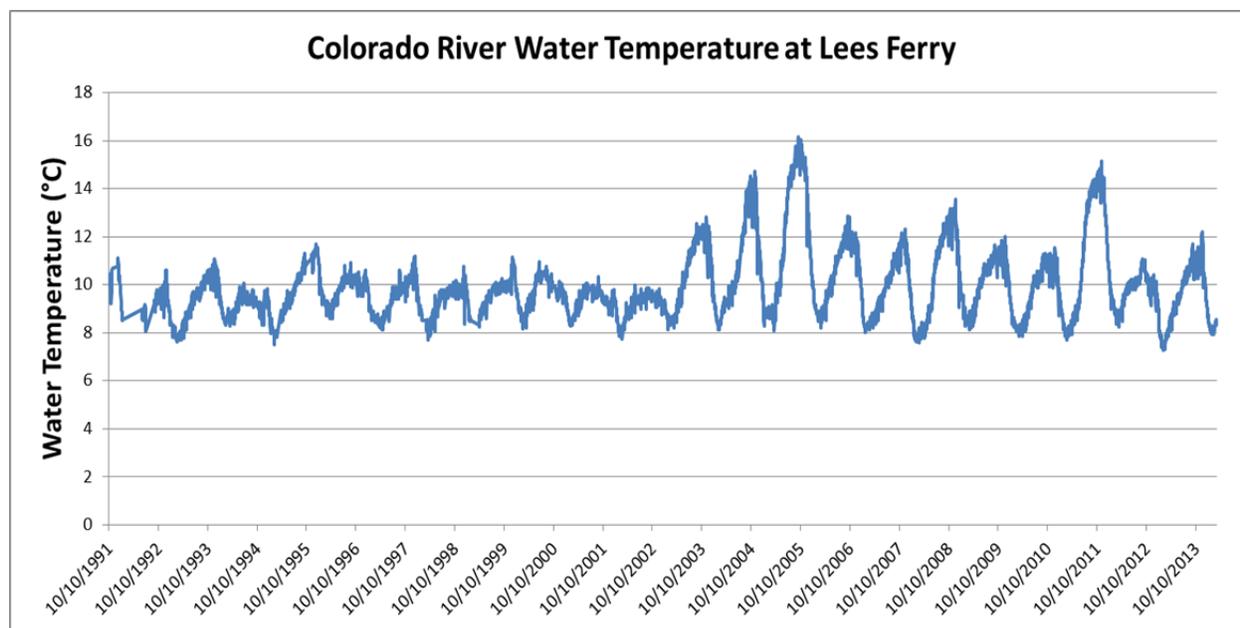


1
 2 **FIGURE 3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado**
 3 **River (Source: Vernieu et al. 2005)**
 4
 5

6 snowpack in the Colorado Mountains which resulted in higher inflows to Lake Powell and
 7 unusually large releases of warmwater.
 8

9 Because of the position of the penstocks (i.e., elevation 3,470 ft), water temperatures can
 10 vary both annually and throughout the course of a year because the locations of the epilimnion,
 11 metalimnion, and hypolimnion (Figure 3.2-4) depend on season, reservoir level, hydrodynamics,
 12 timing and strength of stratification, and magnitude of withdrawals (Vernieu et al. 2005). When
 13 reservoir levels are high, releases tend to originate from within the hypolimnion and releases are
 14 cooler; when levels are low, withdrawals may come from the metalimnion or upper hypolimnion
 15 and releases are warmer (Hart and Sherman 1996). It appears that the water quality of
 16 Lake Powell above the dam has been largely unaffected by dam operations, particularly since
 17 1991. Instead, the water quality of the reservoir appears to be more strongly linked to annual to
 18 decadal climatological variations, inflow hydrodynamics, and continuing basin-wide depletions
 19 (Lovich and Melis 2007; Hueftle and Stevens 2001; Vernieu and Hueftle 1998).
 20

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



1

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

3

4

5

the reservoir and result in increased advection, or the movement of horizontal currents through
6 the reservoir, at withdrawal-structure elevations (Vernieu 2010).

7

8

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

12

13

14

3.2.2.2 Colorado River Water Quality

15

16

Since the filling of Lake Powell, water quality conditions in the Colorado River below
17 Glen Canyon Dam have changed substantially. Before Glen Canyon Dam was constructed, the
18 river was characterized by wide fluctuations in flow, sediment load, temperature, and salinity
19 content. The construction of the dam in 1963 resulted in the moderation and/or overall reduction
20 of many water quality parameters. Today, the limnology and stratification of Lake Powell,
21 particularly with respect to the location of the penstock intakes, defines the quality of Glen
22 Canyon Dam releases. In general, outflow waters are drawn from the deep zone of the forebay
23 metalimnion into the hypolimnion and characterized as generally even in quality throughout the
24 year, being uniformly cold, clear, and low in DO and nutrients (refer to individual Lake Powell
25 parameters in Section 3.2.2.1 for more details). In addition, operation of the dam for peaking
26 power generation has resulted in the removal of much of the seasonal and annual variability that
27 occurred under natural conditions, replacing it with daily fluctuations constrained by set ramping
28 rates (Vernieu and Hueftle 1998; Lovich and Melis 2007). After its release from the dam,
29 changes to the chemical and physical quality of the water are affected by ambient meteorological

1 conditions, primary production and respiration from the aquatic environment, aeration from
2 rapids, inputs from other tributary sources and overland flow, and various aspects of dam
3 operations (Vernieu et al. 2005).
4

5 Previous HFEs have been shown to affect the water quality of Lake Powell, the release
6 waters, and Colorado River below Glen Canyon Dam, resulting in slight reductions in
7 downstream temperature and slight increases in salinity, as well as a temporary increase in
8 turbidity (i.e., suspended sediment) from scouring (Reclamation 2011b). In addition, under
9 normal powerplant discharges, limited aeration of the river occurs in the tailwater reach of the
10 river just below the dam compared to reaches farther downstream. However, during HFEs
11 (e.g., high flows in 1996, 2004, 2008, 2012, 2013, and 2014), the effects of the spray and
12 resulting turbulence were sufficient to bring the undersaturated release water up to full or
13 supersaturation oxygen levels immediately below the dam and through the tailwater (Hueftle and
14 Stevens 2001; Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). During HFEs, diurnal DO
15 patterns were still present but were overshadowed by jet tube aeration. These fluctuations
16 recover quickly (within hours) when there is a return to lower flows, although net respiration is
17 typically reduced from pre-flood levels due to the sheared biomass (Hueftle and Stevens 2001).
18 The magnitude of the dam discharges also influences the amount of sediment in suspension, and
19 high water volumes can greatly affect the degree of downstream distribution. Large or widely
20 fluctuating releases draw water from a thicker withdrawal zone than do low or steady releases.
21 Thus, during these events, water has the potential to be either cooler and more saline (if drawn
22 from below the thermocline or released through the jet tubes) or warmer and less saline (if drawn
23 from above) than that typically released (Vernieu et al. 2005).
24

25 Downstream of the dam, larger tributaries (e.g., Little Colorado River and Paria River)
26 that enter the Grand Canyon can affect water quality of the Colorado River below Glen Canyon
27 Dam. In general, these tributaries tend to carry water at higher temperatures than the mainstem
28 river, thus warming the regions where they join. In addition, tributaries, such as Paria River and
29 Little Colorado River, can carry large amounts of fine sediment and organic materials during
30 flood events, which limit light availability for primary production and may enhance conditions
31 for native fish that use turbid water for cover from predation (Cole and Kubly 1976;
32 Shannon et al. 1994; Topping et al. 2000a,b; Vernieu et al. 2005). Some tributaries, such as the
33 Little Colorado River, are also significant sources of salinity for the mainstem Colorado River,
34 while other tributaries are more dilute (Cole and Kubly 1976; Vernieu et al. 2005). There are also
35 a number of smaller spring-fed tributaries that originate within the Grand Canyon reach, which
36 tend to have very different physicochemical properties than the mainstem; however, their mean
37 flows are so low that their contribution to water quality during base flow is not significant.
38
39

40 **Colorado River Temperature**

41

42 Prior to the construction of Glen Canyon Dam, the water temperatures of the Colorado
43 River in the Grand Canyon would range from near freezing (0°C, or 32°F) in the winter to
44 around 30°C (86°F) in the late summer, with a mean of approximately 14°C (57°F) (Cole and
45 Kubly 1976; Johnson and Merritt 1979; Reclamation 1995; Vernieu and Hueftle 1998; Lovich
46 and Melis 2007; Stevens 2007). Before 1973, during the reservoir's initial filling stage, release

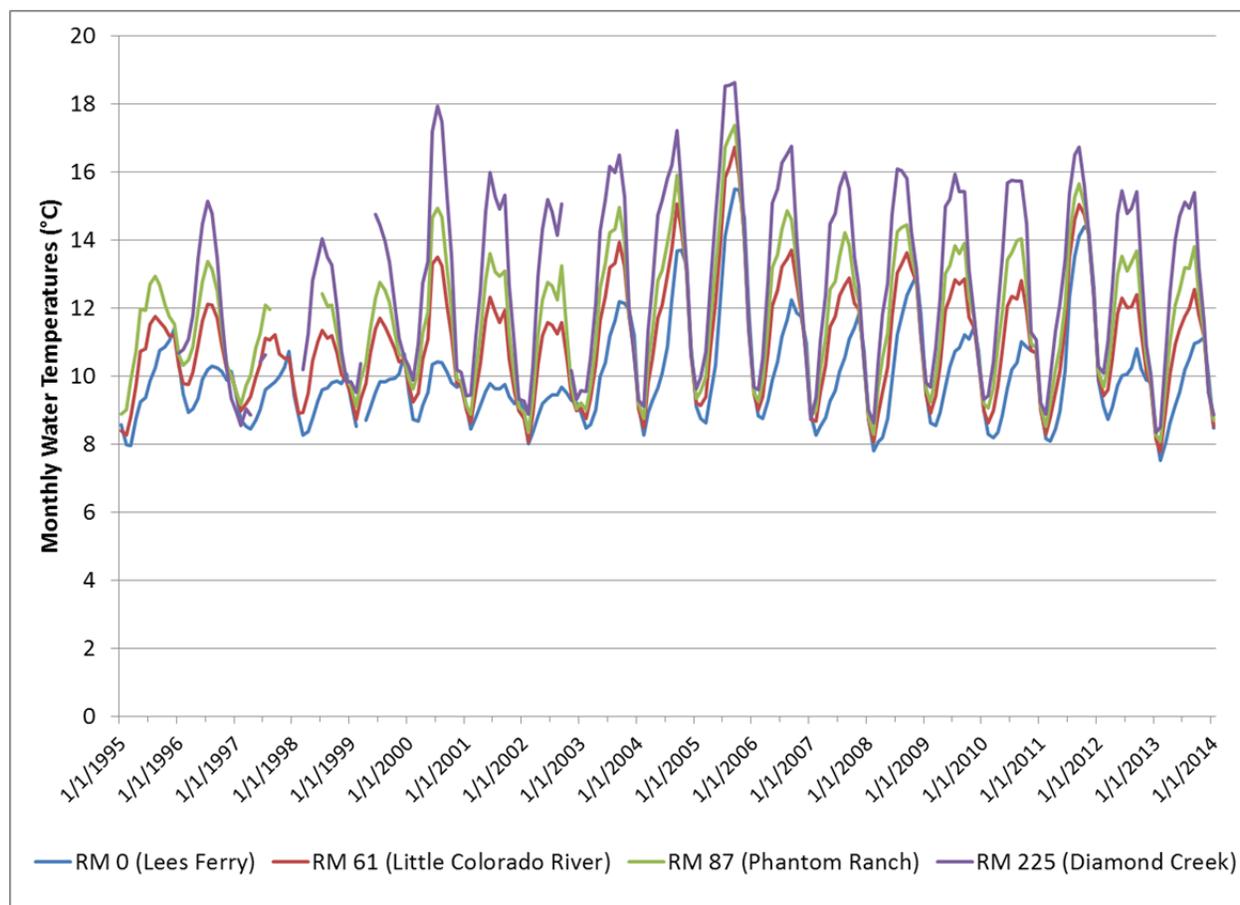
1 temperatures were greatly affected by surface or epilimnetic withdrawals because of the
2 proximity of the reservoir's surface to the penstock withdrawal zone. Thus, the maximum release
3 temperatures during that period occurred during the months of August and September, reflecting
4 the surface warming of the reservoir (Vernieu et al. 2005).
5

6 Trends in tailwater temperature stabilized from 1973 to 2003, when the reservoir surface
7 elevations were above 3,600 ft. During this time, overall seasonal fluctuations diminished to
8 approximately 5°C (9°F), and release temperatures were greatly reduced because the penstocks
9 of the dam were located well below the surface of Lake Powell in the hypolimnion. The Glen
10 Canyon Dam tailwater temperatures ranged between about 7 and 12°C (45 and 54°F) and
11 averaged about 9°C (49°F) as measured at Lees Ferry, with minor excursions beyond this range
12 during periods of spillway releases (Reclamation 1995, 1999b; Vernieu et al. 2005;
13 Hamill 2009). In addition, an asymmetric annual temperature pattern developed over this period,
14 with tailwater temperature measurements reflecting the seasonal changes of the water at the
15 penstock depth. In general, the highest river temperatures immediately below the dam occurred
16 in late fall or early winter (e.g., December), instead of in summer, which is when they occurred
17 in the pre-dam, unregulated river. This warming pattern is most likely a result of winter vertical
18 mixing in the upper layers of the reservoir, which gradually draws the relatively warm, summer
19 epilimnion water to levels at or near the penstock. This is followed by a sudden drop of the
20 river's minimum temperature within a few months, with the lowest temperatures occurring in
21 late winter (e.g., February or March), that likely occurs due to reservoir mixing (Vernieu and
22 Hueftle 1998). Daily warming of the tailwater has also been observed, with the maximum
23 warming (about 1.3°C, or 2.3°F) during the day occurring in June, near the summer solstice
24 (Flynn et al. 2001).
25

26 Since the early 2000s, total Colorado Basin storage has experienced year-to-year
27 increases and decreases in response to wet and dry hydrology. However, Lake Powell water
28 levels have generally declined as a result of basin-wide drought conditions, and subsequently
29 release temperatures warmed. For example, in November 2004, the annual maximum mean daily
30 temperature reached its height at around 15°C (59°F) (Vernieu et al. 2005) at the Little Colorado
31 River. Beginning in water year 2005, overall reservoir storage in the Colorado River Basin has
32 increased (Reclamation 2013c), which has apparently caused river temperatures to decline
33 slightly, although they still range between around 8 and 12°C (46 and 57°F) at Lees Ferry.
34 Figure 3.2-5 (in Section 3.2.2.1) presents the water temperatures measured at Lees Ferry from
35 1991 to 2013, which illustrates the aforementioned warming trend of dam releases.
36

37 River temperatures increase as the water moves slowly downstream. This correlation is a
38 function of the distance and time from Lake Powell, as well as the input from tributaries (which
39 are usually warmer than the mainstem) (Cole and Kubly 1976). However, it has been generally
40 estimated that water temperatures increase about 1°C (1.8°F) for every 30 mi traveled
41 downstream (Reclamation 1999b). This downstream warming trend can be seen in Figure 3.2-6,
42 which presents Colorado River water temperatures at four stations along the river from
43 Lees Ferry to Diamond Creek.
44

45 The greatest warming occurs during the period from June through August because of the
46 transfer of heat from the warmer surrounding air mass, heat stored in the canyon walls adjacent



1

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

4
5

6 to the river, and solar radiation. The mean annual downstream river temperatures ranged between
 7 9 and 18°C (48 and 64°F), depending on year and distance downstream of the dam
 8 (Reclamation 1995, 1999b; Hamill 2009). In general, water temperature in lower reaches of the
 9 river is affected by three physical properties: discharge rate, which affects residence time
 10 (Anderson and Wright 2007; Wright, Anderson et al. 2008); channel aspect, which affects light
 11 availability; and air temperature, which is generally greater in the western portion of the Grand
 12 Canyon (Yard et al. 2005; Ralston 2011). Mainstem water temperatures near the mouth of the
 13 Little Colorado River have not reached 16°C (61°F) in July and August unless release
 14 temperatures approached 14°C (57°F) (Wright, Anderson et al. 2008). Warmer mainstem
 15 temperatures are attainable in the western part of the Colorado River in July, when releases from
 16 Glen Canyon Dam are 12°C (25°F), because of the longer residence time of water in the river
 17 channel (Ralston 2011).

18

19 As illustrated in Figure 3.2-7, a comparison of the increase in weekly average water
 20 temperature between Glen Canyon Dam and Diamond Creek to the average weekly flow during
 21 mid-June from 1994 to 2004 demonstrates the effect of Glen Canyon Dam releases on warming
 22 patterns in the Colorado River in the Grand Canyon. For example, the 1997 high steady flows of

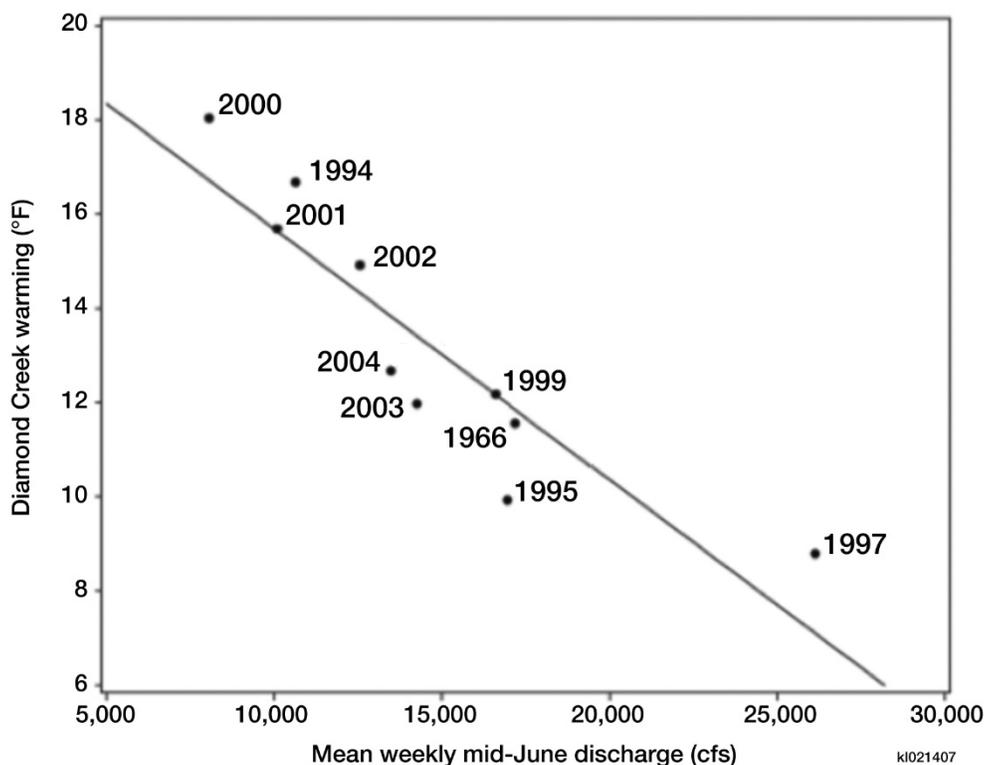


FIGURE 3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek, 1994–2004, as a Function of Mean Weekly Discharge (Source: Vernieu et al. 2005)

approximately 26,000 cfs resulted in 5°C (9°F) warming at Diamond Creek, whereas the low steady flows of 8,000 cfs in 2000 exhibited a 10°C (18°F) warming. This difference is because large volumes of water have greater mass and a lower surface area to volume ratio, as well as less residence time for atmospheric heat exchange that is due to higher velocity, reducing the amount of warming from ambient temperatures and solar radiation. The warming occurring at low discharges also affects water temperatures in the lower Grand Canyon to a greater degree than the elevated release temperatures (Vernieu et al. 2005).

Lateral variation in river temperature has also been found to occur throughout the Grand Canyon. Substantial warming takes place in various near-shore environments, ranging from shallow, open-water areas to enclosed backwaters. Water in these environments becomes isolated from mixing with the main channel current and warms (depending on the season) as a result of solar radiation and equilibration with ambient air temperatures (Vernieu et al. 2005; Ralston 2011). According to 2000 data, water-surface temperatures along the shorelines varied from 9 to 28°C (48 to 82°F), with temperatures between 13 and 14°C (55 and 57°F) accounting for the largest proportion of all shoreline areas (Davis 2002; Ralston 2011). Backwaters specifically showed the largest contiguous areas with surface temperatures greater than 16°C (61°F) during the warmest periods. In addition, the area near the confluence with the Little Colorado River shows significant local warming as a result of the tributary inflow. According to 2000 data, mainstem surface temperatures near the Little Colorado River averaged about 13.5°C

1 (56°F), because the cooler mainstem temperatures (typically 12°C [54°F], even in the summer
2 months) are mixed with than those of the warmer tributary (typically greater than or equal to
3 16°C [61°F]) (Voichick and Wright 2007; Protiva et al. 2010; Ralston 2011). In contrast to the
4 mainstem, the Little Colorado River and other tributaries do not appear to have much interannual
5 variation in the range of natural variability after 1990, when regular monitoring began
6 (Stevens 2007).
7
8

9 **Colorado River Salinity**

10
11 Since the construction of Glen Canyon Dam, the existence of Lake Powell and the
12 amount of water passing through the system has acted to moderate and stabilize salinity levels in
13 both the reservoir and the tailwater (Reclamation 1999b). Salinity below Glen Canyon Dam is
14 typically in the range of 300–600 mg/L for total dissolved solids (TDS), with sodium and
15 calcium as the dominant cations and sulfate as the dominant anion (Hart and Sherman 1996;
16 Taylor et al. 1996; Vernieu et al. 2005; Reclamation 1999b, 2005, 2011c; CRBSCF 2011). The
17 U.S. Environmental Protection Agency (EPA) has not set a primary drinking water standard for
18 salinity; however, this information indicates that the EPA’s secondary drinking water standard of
19 500 mg/L for TDS (EPA 2012a) may be exceeded at some areas along the river, particularly
20 during dry periods (Reclamation 2011c).
21

22 The specific conductance of the Colorado River between the Glen Canyon Dam and Lake
23 Mead has been found to range from 310 to 4,600 $\mu\text{S}/\text{cm}$ (approximately 200–2,700 mg/L TDS),
24 with the lowest levels near the mouth of Bright Angel Creek and highest concentration near the
25 mouth of the Little Colorado River (Taylor et al. 1996; Voichick 2008; Hart and Sherman 1996).
26

27 Research has indicated that salinity below the dam changes little with the seasons and
28 shows no regular daily pattern (Flynn et al. 2001; Reclamation 1995). In fact, post-dam salinity
29 fluctuations downstream vary less over several years than the pre-dam cycles changed on the
30 order of months (Reclamation 1995). However, large or widely fluctuating releases draw water
31 from a thicker withdrawal zone than do low or steady releases. Thus, during these events, water
32 has the potential to be either cooler and more saline (if drawn from below the thermocline or
33 released through the jet tubes) or warmer and less saline (if drawn from above) than that
34 typically released (Vernieu et al. 2005).
35
36

37 **Colorado River Turbidity**

38
39 Turbidity levels are of interest in the downstream environment because water clarity
40 affects the amount of light available for photosynthesis for downstream algal communities,
41 which are an important part of the overall food base for native and nonnative fishes. Turbidity
42 also affects the behavior and distribution of various native and nonnative fishes in providing
43 cover from various predators or by affecting sight-feeding abilities (Vernieu et al. 2005).
44 Turbidity is related to several characteristics of suspended sediment (as noted above in
45 Section 3.2.2.2); thus, suspended-sediment measurements have been used as a proxy for
46 determining turbidity in the system. Voichick and Topping (2010) specifically correlated these

1 two values for the Grand Canyon section of the Colorado River and determined a statistically
2 significant relationship between them.

3
4 Prior to construction of Glen Canyon Dam, the Colorado River has historically had very
5 turbid water with suspended load averaging between 1,450 and 6,140 mg/L , depending on
6 month, at Lees Ferry (data for the years 1930–1964) (USGS 2013a) and around 8,000 mg/L
7 downstream 80 mi (Cottonwood Creek), with a maximum historical record of more than
8 150,000 mg/L measured between the mouth of the Little Colorado River and Bright Angel Creek
9 (Cole and Kubly 1976; Johnson and Merritt 1979).

10
11 In the post-dam river, the annual supply of sediment has been altered and reduced. More
12 recent measurements have found the concentration of suspended sediment at Lees Ferry to range
13 from approximately 1 to 150 mg/L (data for the years 1996–2012) (Reclamation 2002;
14 USGS 2013b). The amount of suspended sediment downstream of the dam depends primarily on
15 tributary runoff into the Colorado River below Lees Ferry, which can contribute high
16 concentrations to the mainstem during large floods on those tributaries (Voichick and
17 Topping 2010). It also depends on the magnitude and frequency of planned HFEs, which can
18 temporarily increase suspended sediment as a result of scouring in the reach downstream of the
19 dam. Consequently, suspended sediment varies over an even larger range now than it did prior to
20 the completion of Glen Canyon Dam. Post-dam suspended sediment concentrations near the
21 mouth of the Little Colorado River range from approximately 20 to 133,000 mg/L depending on
22 season and year (Cole and Kubly 1976; Taylor et al. 1996). At Phantom Ranch, approximately
23 87 RM below Lees Ferry and below several tributaries (Paria River, Little Colorado River, and
24 Clear Creek), the suspended sediment concentrations have been found to range from 6 to
25 47,100 mg/L (Reclamation 2002).

26 27 28 **Colorado River Nutrients**

29
30 Nutrients like nitrogen and phosphorous are necessary for healthy waters, but high levels
31 of nutrients can cause a number of problems, ranging from nuisance algae blooms and cloudy
32 water to threatening drinking water quality and harming aquatic life. In general, releases from
33 Glen Canyon Dam and downstream Colorado River waters are relatively low in nutrients.
34 Tributaries below the dam (e.g., Paria River, Little Colorado River) have somewhat higher
35 nutrient contents than the mainstem, but they appear to contribute little to overall mainstem
36 nutrient concentrations (Reclamation 1995). Additional potential point and non-point sources of
37 nutrients to the Colorado River include industrial and municipal wastewater treatment facilities;
38 landfills; urban runoff; septic tanks; irrigated agriculture; fertilizer or manure applications to
39 landscape; animal feedlots; vehicle exhaust; atmospheric deposition; and nitrogen fixation from
40 natural processes (ADEQ 2006a). However, because many of the aforementioned actions take
41 place upstream of Lake Powell, their influence in the Grand Canyon reach is largely via
42 Lake Powell water.

43
44 The high biomass of filamentous green algae (dominated by *Cladophora glomerata* until
45 1995; currently *Ulothrix zonata* and *Spirogyra* spp. dominate) observed in the Glen Canyon
46 stretch of the Colorado River below the dam suggests that nutrients may not be a limiting factor.

1 The uptake and cycling of nutrients may be quick enough that there is very little opportunity to
2 sample free dissolved nutrients in the water column of the river; alternately, delivery rates of low
3 nutrient levels are sufficient for the algae to grow (Reclamation 1999b).

4
5 Research has found that dissolved organic carbon ranged from 2.6–4.2 mg/L in the Glen
6 Canyon Dam outflows and 0.1–3.2 mg/L in the segment between the dam and Lake Mead,
7 although this value may be higher during flood events (Taylor et al. 1996; ADEQ 2006a).
8 Typical concentrations of dissolved organic carbon in rivers ranges from 1 to 20 mg/L, with an
9 average of around 6 mg/L (Maybeck 1982). Phosphate concentrations on the mainstem have
10 typically been found below 0.1 mg/L (Taylor et al. 1996; Hart and Sherman 1996; ADEQ
11 2006a), which is the maximum level recommended by the EPA to control eutrophication
12 (i.e., overabundance of nutrients) and algal growth in streams that do not discharge directly into
13 lakes or reservoirs (Mueller and Helsel 1996). Concentrations of nitrate-nitrogen (NO₃) entering
14 the Colorado River ranged from around 0.13–1.1 mg/L, with the highest levels near the mouth of
15 the Paria River (Taylor et al. 1996; Hart and Sherman 1996). This is well below the EPA
16 established maximum contaminant level (MCL) of 10 mg/L (as nitrogen) for nitrate in drinking
17 water (EPA 2012a). Ammonia concentrations near the source may be as high 2 mg/L, which is
18 dangerous to fish and other aquatic life in the river; however, the threat decreases downstream as
19 the ammonia oxidizes into nitrates in the river (Mueller and Helsel 1996; ADEQ 2006a). In
20 general, dissolved ammonia levels in the tailwater were less than the minimum reporting level of
21 approximately 0.01–0.02 mg/L (Taylor et al. 1996; Hart and Sherman 1996).

22 23 24 **Colorado River Dissolved Oxygen**

25
26 As stated above, the ideal DO for fish, particularly those in early life stages, is between
27 7 and 9 mg/L; most fish cannot survive when DO falls below 3 mg/L. DO concentrations in the
28 Glen Canyon Dam tailwater at Lees Ferry typically range from a low of around 5–6 mg/L in the
29 fall (e.g., October–November) up to a high between 9–11 mg/L in the spring (e.g., April–May)
30 (GCMRC 2015a). However, it is significant to note that unintentional fish kills in the Lees Ferry
31 reach were documented in 2005 as a result of low DO levels, and DO levels in 2014 approached
32 the lethal limit for trout (Arizona Council of Trout Unlimited, Inc. 2015). Thus, while DO levels
33 over the long term do not typically affect the aquatic ecosystem in Grand Canyon, short-term low
34 DO events can have a catastrophic impact on fish.

35
36 The seasonal variation in Colorado River DO reflects changes in the DO concentration in
37 the water of Lake Powell at the depth of the penstocks (Flynn et al. 2001). In general, Lake
38 Powell DO concentrations are at their highest near the surface of the lake in the spring to early
39 summer when inflows are well oxygenated and photosynthetic activities, atmospheric reaeration,
40 and wind-induced mixing are high. During the summer and into the fall, the DO concentrations
41 decrease, primarily as a result of biological reactions. Then, by early winter when the
42 temperatures drop, DO concentrations gradually increase as a result of the higher oxygen-
43 carrying capacity of coldwater and natural mixing processes created by the winter underflow
44 current (Johnson and Merritt 1979; Vernieu and Hueftle 1998). In addition, as the reservoir ages
45 or if there are periods of extended drought, the chances of low-DO (less than 3 mg/L) water
46 being released from the dam increase (Vernieu et al. 2005).

1 In general, depending on the season, DO concentrations increase with distance
2 downstream as a result of aeration from water movement and turbulence. DO concentrations also
3 vary directly with discharge (DO increases with increasing discharge) immediately below the
4 dam and in Glen Canyon. Concentrations typically reach full saturation around the first rapids in
5 Marble Canyon (Reclamation 1995; Vernieu et al. 2005). As previously noted, HFEs can also act
6 to increase oxygen levels immediately below the dam and through the tailwater; however, these
7 effects will recover quickly when there is a return to lower flows (Hueftle and Stevens 2001;
8 Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). Daily oscillations in DO in the tailwater
9 have also been observed at Lees Ferry as a result of activity by the Colorado River benthic
10 community. During daylight hours, DO concentrations increase through photosynthesis; at night,
11 a decrease in DO occurs when respiratory processes become dominant (Flynn et al. 2001;
12 Vernieu et al. 2005). The amplitude of the daily DO change at Lees Ferry ranges from around
13 0.5 mg/L to more than 3.0 mg/L depending on season, with the lowest fluctuations occurring in
14 winter and greatest in spring and summer (GCMRC 2015a).

17 **Colorado River Bacteria and Pathogens**

18
19 The Grand Canyon's water quality varies greatly in terms of bacteria and pathogens. As
20 development and recreation along the river continue, the potential for an increase of bacterial
21 contamination will continue. Coliform bacteria are a large group of bacterial species that are
22 most commonly associated with water quality. *Escherichia coli* (*E. coli*), one species of fecal
23 coliform bacteria present in the fecal matter of warm-blooded animals, is commonly used in
24 recreational water quality sampling as an indicator of fecal contamination and the potential
25 presence of other harmful organisms (ADEQ 2006a). For fresh recreational waters, the *E. coli*
26 standard criteria is set at 126/100 mL (3.38 oz), with Arizona further defining a single sample
27 maximum of 235 for full body contact and 576 for partial body contact (EPA 2003).

28
29 Research has indicated that episodic precipitation cycles and arid watershed hydrology
30 are the principal factors influencing occurrence of bacteria in the river system. Bacterial testing
31 has not indicated a chronic problem in the river, although local occurrences of high coliform
32 bacterial count can and have occurred (ADEQ 2006a; NPS 2005a; Dodson 1995; Tinkler 1992).
33 Fecal coliform in the river and in most tributaries were found to range from 10 to
34 20 counts/100 mL (3.38 oz) during drought cycles. During wet cycles and storm flows,
35 fecal coliform densities were highly variable and often exceeded recreational contact standards
36 (Tunnicklif and Brickler 1984).

37
38 Most of the tributaries have high bacterial counts at least some of the time. This bacteria
39 may not be of human origin, but may still result in illnesses. Any stream exhibiting high fecal
40 coliform or fecal streptococcus counts may also carry giardia (NPS 2012a).

43 **3.2.2.3 Lake Mead Water Quality**

44
45 This section describes the historic and existing water quality constituents that could
46 potentially be affected by the proposed federal action. These water quality constituents of

1 concern include salinity, temperature, sediment, and DO. Other water-quality-related issues and
2 parameters were also considered, but they were determined unlikely to be affected by the
3 proposed federal action, or there was insufficient data to provide an assessment and they are
4 therefore not discussed here. As of 2015, increases in Lake Mead temperatures are contributing
5 to the extensive and persistent presence of blue-green algae (i.e., cyanobacteria) throughout Lake
6 Mead, including Gregg's Basin. This algae produces two toxins, microcystin and anatoxin, that
7 can affect humans and wildlife (EPA 2012b).
8

9 The Colorado River is the primary hydrologic input into Lake Mead, providing
10 approximately 97% of the total annual inflow. Thus, it is reasonable to assume that the quality of
11 the Colorado River water flowing into the reservoir will have a significant and direct influence
12 on the resulting water quality of Lake Mead. Although a suite of water quality parameters was
13 evaluated for this EIS, four water quality variables were found to be important relative to the
14 effects of Glen Canyon Dam operations. Temperature, salinity, turbidity, and DO of the inflow
15 of the Colorado River into Lake Mead can be affected, particularly by large-volume flows such
16 as HFEs. Because Lake Mead serves as a water supply for Las Vegas and surrounding areas,
17 changes in Lake Mead water quality have the potential to affect the quality of this water supply.
18

19 Colorado River water is lower, on average, in conductivity (i.e., salinity) than the water
20 in Lake Mead. However, Colorado River water has a higher density due to its lower temperature
21 and, to some extent, its suspended sediment load. As a result, the Colorado River most often
22 enters Gregg Basin as an underflow, which at times can be seen all the way into Boulder Basin
23 and at the Hoover Dam (Turner et al. 2011; Holdren et al. 2012). This phenomenon also limits
24 nutrient availability and productivity in the upper levels of the reservoir.
25

26 The quality of the Colorado River water entering Lake Mead directly influences Lake
27 Mead water quality. During summer months when the temperature differential between Lake
28 Mead and the Colorado River is at its greatest, water entering Lake Mead from the Colorado
29 River plunges to a depth of 65–100 ft in the reservoir's metalimnion, approximately 6 mi
30 downstream of Pearce Ferry (Grand Wash). From this point on, water from the Colorado River
31 exists as a metalimnion interflow and retains its identity, as characterized by lower conductivity,
32 for much of the distance through the reservoir. During winter months, a similar flow pattern
33 occurs; however, the plunge line moves downstream several miles. Cooler winter water
34 temperatures in Lake Mead provide greater mixing due to the decreased amount of energy
35 needed to mix the Colorado River water into the reservoir. Once Colorado River water plunges
36 instead of riding the metalimnion just below the thermocline, it drops to a depth of about
37 260–330 ft, at which point it reaches equilibrium with the lake water. The distance traveled
38 before the plume loses its identity is also shorter in the winter due to greater mixing that occurs
39 then, and because of the reduced temperature differential between the two bodies of water (Horn
40 and LaBounty 1997). Effects on Lake Mead water quality that can occur as a result of changes in
41 dam operations include changes in salinity, turbidity, and DO in the lake (Tietjen 2013). Dam
42 operations can affect temperature.
43

44 As with Lake Powell, the stratification of Lake Mead influences many chemical and
45 biological processes in the reservoir and, consequently, influences the characteristics and quality
46 of water that is released to the Colorado River below the Hoover Dam.

1 The salinity (or specific conductance) of the water in Lake Mead is controlled by a set of
2 interrelated factors, including relatively low values originating from the Colorado River; higher
3 values in the inflow from tributaries other than the Colorado River; evaporation of surface
4 waters; and water column stratification. As a result, salinity concentrations have cycled greatly
5 during this time period, specifically in response to the volume and quality of Colorado River
6 water being released from Lake Powell (Tietjen et al. 2012). For example, as Lake Powell
7 releases water of lower or higher salinity into the Colorado River downstream, the average
8 salinity levels of Lake Mead’s water column will similarly decrease or increase, respectively.
9

10 The formation of Lake Powell in 1963 resulted in marked reductions in suspended
11 sediment loading to Lake Mead, by trapping nearly all of the upstream Colorado River
12 suspended sediment and effectively removing around two-thirds of Lake Mead’s previous
13 sediment-contributing drainage area (Ferrari 2008). It has been estimated that between 1935 and
14 1963, about 0.091 maf of sediment was deposited in Lake Mead each year. However, with the
15 construction of Glen Canyon Dam and the great reduction in suspended sediment load, the life of
16 Lake Mead is now essentially indefinite (Reclamation 2012c). A rough estimate of Lake Mead’s
17 current annual sediment accumulation from the Colorado River in the very upper delta portion of
18 the reservoir is less than 7,200 ac-ft (assumes the continual trapping of sediments in Lake Powell
19 and ongoing consolidation of the finer sediments entering Lake Mead) (Ferrari 2008). The
20 amount of finer material entering and settling in the lower reaches of the reservoir is unknown.
21 Dam operations can affect turbidity of the inflow to Lake Mead. For example, HFEs may
22 produce increased turbidity in the inflow, although this is also influenced by Lake Mead
23 elevation, stratification, and inflow temperature (Tietjen et al. 2012).
24

25 DO concentrations in reservoirs are affected by variations in inflow volume and
26 temperature, seasonal reservoir circulation, and biological production and decomposition. In
27 years of high inflows and when the reservoir elevations are low, flows cut through deltaic
28 sediments, resuspending organic matter and nutrients that contribute to both chemical and
29 biological oxygen demand as the inflow water passes down through the reservoir water column.
30 The resulting plumes of low-oxygen water cause the release of oxygen-poor water. When deltaic
31 sediments and organic matter are not resuspended, oxygen demand is lower and DO
32 concentrations remain higher. Downstream of dams, turbulence, exposure to the atmosphere, and
33 primary productivity re-aerate the water column. The DO concentration reaches saturation
34 downstream of Glen Canyon Dam before the confluence with the Little Colorado River
35 (Vernieu et al. 2005) after passing through several major rapids.
36

37 In Lake Mead, DO concentrations decrease in Boulder Basin as a result of nutrient
38 contributions from Las Vegas Wash and algae growth. In recent years, low DO conditions have
39 been documented in some isolated parts of Lake Mead near the Colorado River inflow. Ongoing
40 monitoring and investigations are being conducted to determine the cause of such decreases,
41 which may be temperature driven. However, DO has not dropped below acceptable minimum
42 levels. Further, DO has not been documented as an issue in downstream reaches.
43
44

3.2.3 Tribal Perspectives on Water Resources

It is important to note that, in the broadest sense, all sources of water (e.g., springs, washes, ponds, pools, lakes, and rivers) are culturally and spiritually important to American Indian Tribes.

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

The Havasupai are the Havsu w 'Baaja, the people of the blue-green water in their native language. They consider the river the backbone, or *Ha'yidada*, of the landscape and to have healing powers (NPS 2006a). Today, this is symbolized by its placement in the center of the Hualapai seal (Hualapai Tribe 2013). The Hualapai worldview holds that the Colorado River provides a life connection to the Hualapai as it flows through the landscape, connecting the canyon and the riparian ecosystems that sustain the Tribe. The historic trails in the canyons and across the Coconino Plateau include sacred springs as stopping points. The Havasupai religion and culture are closely connected to springs through songs and stories (Hirst 1985).

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

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

1 manner, the Creator will become disappointed or angry and withhold food, health, and power
2 from humans.”

3
4 Zunis pray for water; they pray at water
5 sources; and they use water in religious
6 ceremonies. Cushing wrote that the Zuni
7 “consider water as the prime source of life”
8 (Green 1979). As Dickie Shack, a Zuni religious
9 leader and cultural advisor, explained, “The
10 whole world has water and it’s all precious to us.
11 We get it and bring it here for our religious stuff.
12 We use it in paint for our prayer sticks—it’s so
13 important to get rain. So this water is precious to
14 us. If I go to the Grand Canyon, I’ll get me water
15 there. I believe the rain is our fathers. Anywhere
16 there are springs we hold out hand and say,
17 ‘come with us to Zuni village’ and we pour the
18 water on our heads.” Mr. Shack added, “In my
19 Rain Priest doings, we pray for all directions, to
20 the ocean, to our grandfather, Ko’lowisi, the
21 serpent, in all directions. We say prayers so that
22 they’ll help us with rain. So all this water around
23 the world, even the ponds, it’s very important to
24 us, for us to say prayers because we need rain in
25 Zuni” (Colwell-Chanthaphonh et al. 2011).

26
27 Further emphasizing the importance of all
28 water life to the Ne’we:kwe Medicine Society,
29 the textbox provides an excerpt from one of the
30 ceremonial prayers shared by Seowtewa.
31 Speaking about Glen Canyon Dam, Seowtewa
32 stated, “They put the dam in without
33 consultation, and ... the dam restricted the
34 umbilical cord. It’s like when you’re in your
35 mother’s womb and there’s a knot in the cord,
36 then there’s a problem” (Colwell-
37 Chanthaphonh et al. 2011).

38 39 40 **3.2.4 Hydrology and Climate Change**

41
42 Climate models project that temperatures
43 will increase globally by about 1 to 2°C (1.8 to
44 3.6°F) over the next 20 to 60 years. Although
45 global predictions and trends cannot predict
46 changes at the regional level with certainty,

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

*When the world was created, within the four Great
Oceans and waterways (North Pole, South Pole,
and Atlantic, Pacific Oceans)*

Our Father that stayed behind and flourished

The Feathered Serpent

The Water Snakes

The Fish

The Turtle

The Tadpoles

The Toads

The Frog

The Water Boatman and all aquatic life . . .

And all the protectors of the waters

The Crane

The Geese

The Ducks

The Coots

The Grebes

The Orioles

The Mockingbirds

The Nuthatch

The Wren

The Egrets

The Father Sun – Mother Moon

The Creator

These are the Givers of the Breath of Life

The Aged and the Wisdom

The Water of Life

The Seed of Life

The Belongings of Life

The Offsprings of Life

The Strength

And the rest of the Givers of Life

I ask for their breath

*If all goes accordingly and the breath of our fathers
are respected*

We will all see our fathers rising and setting sun

Arm in Arm

Strength in connection

We will all grow old in wisdom

Now I ask the fathers for that Breath

For the Breath of Life for all

1 regional temperatures are also expected to increase. Average estimates for the Colorado River
2 Basin indicate a projected 5 to 6°C (9 to 10.8°F) increase during the 21st century, with slightly
3 higher increases projected in the upper Colorado Basin (Reclamation 2011e). Predictions also
4 suggest a general drying trend (although the full range of predictions includes both wetter and
5 drier conditions) for mid-latitude areas such as the Colorado River Basin (Reclamation 2007a;
6 Vano et al. 2013; IPCC 2007).

7
8 Observations and studies have also shown that many natural systems are being affected
9 by regional climate changes, particularly the aforementioned temperature increases, and that
10 these changes will likely affect the hydrological cycle, with associated impacts on water
11 resources. The following sections summarize the potential effects of increasing temperatures on
12 the broad-scale features of Colorado River Basin hydrology and water resources; other aspects
13 related to climate change (e.g., meteorology and air quality) are discussed in Section 3.16 of
14 this EIS.

15 16 17 **3.2.4.1 Basis for Runoff Estimates**

18
19 The most likely hydrological changes expected as a direct consequence of warmer
20 temperatures are linked to water variability and availability (described in more detail in
21 Section 3.2.4.2), which is mostly influenced by the amount of runoff in the basin
22 (Reclamation 2007c). The conventional assumption used in water resources planning is that the
23 past record of runoff can be used to represent future conditions; in other words, that the future
24 will look like the recent past. However, there are limitations to these assumptions; it is possible
25 that future flows may include periods of wet or dry conditions that are outside the range of
26 sequences observed in the historical record, particularly considering the effects of climate change
27 and the potential for increased hydrologic variability. Furthermore, considerable evidence from
28 paleontological records indicate that the observed record of the last 100 years does not capture
29 the full range of variability of historical stream flows in the Colorado River (Reclamation 2007c;
30 Vano et al. 2013). In fact, the early 20th century, which is the basis for water allocation decisions
31 in the basin, was a period of unusually high flow (Vano et al. 2013). Tree ring records indicate
32 that the Colorado River Basin has experienced severe droughts in the past and could do so again,
33 even without human-caused climate change (Vano et al. 2013). Thus, although paleoclimatic
34 information may not necessarily represent future climate conditions, this information is valuable
35 and may be useful in understanding variability in future hydrologic sequences, particularly with
36 respect to the potential for drought (Reclamation 2007a).

37 38 39 **3.2.4.2 Water Variability and Availability**

40
41 In general, the water supply of the Basin is strongly dependent on snowmelt from high-
42 elevation portions of the Upper Basin, with about 15% of the watershed area producing about
43 85% of the entire basin's average annual runoff. Annual precipitation ranges from less than 4 in.
44 in southwestern Arizona to nearly 63 in. in the headwaters in Colorado, Utah, and Wyoming
45 (Reclamation 2011e). The western states have heated up more than the world as a whole has
46 (Saunders et al. 2008). In 2003–2007, the global climate has averaged 1°F warmer than the

1 20th century average. For the same period, the 11 western states averaged 1.7°F warmer than the
2 20th century average. By state, average temperature increases range from 1.3°F in New Mexico
3 to 2.2°F in Arizona. To date, decreases in snowpack, less snowfall, earlier snowmelt, more
4 winter rain events, increased peak winter flows, and reduced summer flows have been
5 documented (Saunders et al. 2008).
6

7 Water storage is very sensitive to changes in mean inflows and to sequences of wet and
8 dry years. As noted previously, although precise regional estimates of the future impacts of
9 climate change on runoff throughout the Colorado River Basin at appropriate spatial scales are
10 not currently available, these impacts may include decreased mean annual flow and increased
11 variability, including more frequent and severe droughts. Overall changes to precipitation would
12 likely decrease the rain and snow that drains into the Colorado River Basin; however, estimates
13 have suggested that by 2050 Upper Basin precipitation may increase slightly (i.e., 2.1%), while
14 that in the lower basin declines similarly (i.e., 1.6%) (Reclamation 2011e). Furthermore, warmer
15 temperatures alone would be expected to increase water losses (e.g., evapotranspiration from
16 vegetation, evaporation from reservoirs, and sublimation) and reduce runoff flow
17 (Reclamation 2007a; Vano et al. 2013; Reclamation 2012e).
18

19 Estimated declines of future runoff for the Colorado River Basin range from less than
20 3.5% to 45% by the mid-21st century (Vano et al. 2013; Reclamation 2011e). The wide range in
21 projected flow decreases results from the following factors:
22

- 23 • Variability among climate models and future emissions scenarios used to
24 generate the estimates;
25
- 26 • Spatial resolution of the model, which is important for capturing topography
27 and its effect on the distribution of snow in the Colorado River's mountainous
28 headwaters;
29
- 30 • Representation of land-surface hydrology, which determines how precipitation
31 and temperature changes affect the land's ability to absorb, evaporate, or
32 transport water;
33
- 34 • Methods used to statistically downscale from the roughly 124-mi resolution
35 used by global climate models to the 6.2- to 12.4-mi resolution used by
36 regional hydrology models; and
37
- 38 • Model uncertainties, including the uncertainty in the climate response, as well
39 as the uncertainty due to differences in methodological approaches and model
40 biases (Vano et al. 2013; Reclamation 2007a).
41

42 The general picture for climate change, as it relates to Colorado River Basin hydrology,
43 includes decreased inflow to the reservoir system (due to lower precipitation), greater
44 evaporation and evapotranspiration losses (due to higher temperatures), and increased demand
45 (due to increased population size). Combined, these factors increase the probability and likely
46 duration of delivery shortages in coming decades. It has been estimated that the shortfall created

1 by future supply and demand imbalances could range from 2.3 to 4.1 maf per year, during any
2 given deficit period (Reclamation 2012e). When climate change considerations are taken into
3 account, this value increases to around 7.4 maf per year during the deficit period
4 (Reclamation 2012e).

7 **3.2.4.3 Seasonal Timing Shifts**

8
9 Warmer conditions are also expected to lead to shifts in the precipitation events and
10 seasonal timing of runoff (i.e., transitioning snowfall to rainfall) with increased winter runoff
11 (December to March) and decreased summer runoff (April to July) (Reclamation 2011d,e,
12 2013c; Brekke et al. 2009). This shift in timing could present challenges in managing
13 streamflow, especially under current reservoir operational constraints. Storage opportunities
14 during the winter runoff season currently are limited by flood-control considerations, and
15 increased winter runoff under climate change will not necessarily translate into increased storage
16 of water leading into the spring season. Conversely, reservoir storage capture of snowmelt runoff
17 traditionally has occurred during the late spring and early summer seasons. Reductions in runoff
18 during this season likely would translate into reductions in storage capture and, likewise,
19 reductions in water supply for warm season delivery (Reclamation 2013b). Increasing
20 temperature may also increase potential evapotranspiration from vegetation and land surfaces
21 and may thereby decrease the amount of water that then reaches streams, lakes, and reservoirs
22 (Brekke et al. 2009).

23
24 There may also be changes in seasonal patterns in relation to extremes of precipitation.
25 Depending on location, these possible changes can and have led to concerns that droughts and
26 floods, defined relative to past experiences, will occur more frequently and/or be more severe
27 under future climate conditions. However, because of uncertainties in climate models and flood
28 record analyses, the nature of changes in specific locations remains uncertain and will require
29 detailed study (Brekke et al. 2009).

31 32 **3.2.4.4 Water Quality**

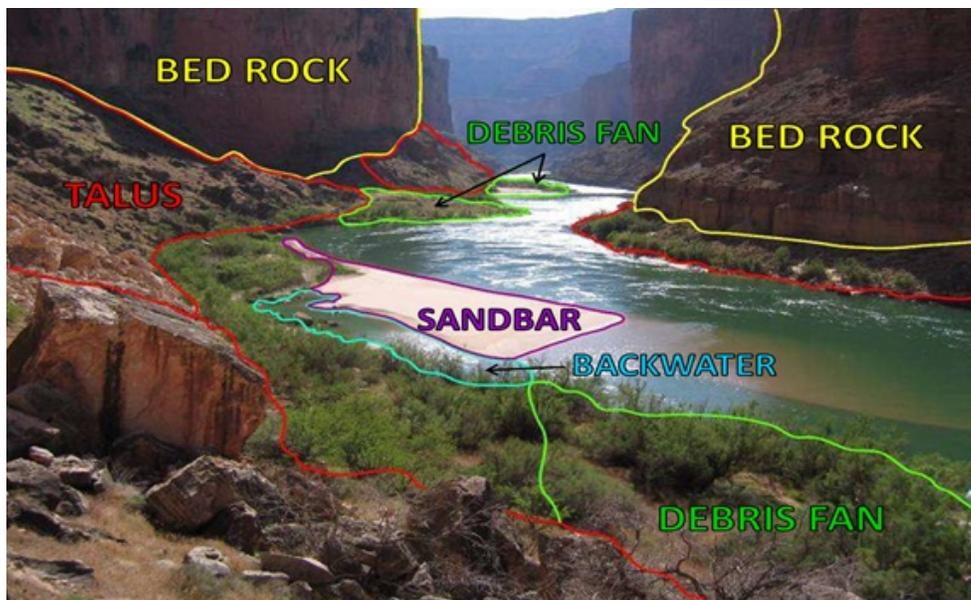
33
34 Water quality is also greatly affected by the changing precipitation and temperature that
35 result from climate change. For example, increasing air temperatures may lead to increased water
36 temperature, which can affect the chemical properties of water and habitat suitability. Altered
37 water temperature in the reservoirs also influences the potential for algal blooms, which can
38 further reduce oxygen levels. In addition, changes to precipitation intensity and frequency
39 (i.e., water availability) can also influence concentrations of suspended sediment, nutrients, and
40 chemical contaminants originating from tributaries, as well as non-point-source pollution from
41 runoff (e.g., agricultural fields, roads, and other land surfaces) (Brekke et al. 2009).

1 **3.3 SEDIMENT RESOURCES**
2

3 This section describes the sediment resources of the affected area. Sediment is defined as
4 unconsolidated material derived from the weathering of rock that is transported and deposited by
5 water or wind. Sediments can be described based on their particle size such as clay, silt, sand,
6 gravel, cobble, and boulder (Section 3.3.2.1). In this DEIS, the use of the term sediment refers to
7 the full range of sediment sizes found in Glen, Marble, and Grand Canyons and references
8 specific sediment size ranges using the terminology described in Section 3.3.2.1. For this DEIS,
9 the sediment size of greatest concern is sand. Dam operations have an important effect on sand
10 distribution in the affected area, and sand transport and deposition is greatly affected by the
11 characteristics of dam operations. Sand deposits above the elevation of normal operations
12 provide for important areas for vegetation, wildlife, and visitors to GCNRA and GCNP.
13

14
15 **3.3.1 Background: Geomorphology of the Colorado River**
16

17 Geomorphology describes the geologic evolution and configuration of landforms and the
18 processes that shape them. The processes by which sediment is formed, transported, and
19 deposited within the system are largely functions of the geomorphic setting through which the
20 Colorado River and its tributaries flow, and the characteristics of rock formations, faulting, and
21 fluvial processes. These factors generate several distinct geomorphic features, such as turbulent
22 rapids, tranquil pools, talus slopes (rock slides), channel-margin areas, terraces, canyon walls,
23 debris-flow deposits, fan-eddy complexes, and sandbars (see Figure 3.3-1). There have been
24 numerous studies regarding these geomorphic features within Glen, Marble, and Grand Canyons.
25 This research has been used to develop conceptual models of how these geomorphic features
26 interact with river hydraulic and sediment-transport processes.
27
28



29
30 **FIGURE 3.3-1 Geomorphic Features of the Colorado River**

1 The Colorado River is sinuous as it flows through the project area, its path being defined
2 by canyon walls. Below Glen Canyon Dam, the river varies with respect to its channel geometry
3 (width, depth, and slope), sediment inputs, bed materials, and hillslope deposits, as well as the
4 topography and geology of the surrounding watershed. Valley width is most affected by the type
5 of rocks near the river level, such that resistant rocks exposed at or near river level
6 (e.g., Vishnu Schist) create narrow valleys, and easily eroded rocks (e.g., Bright Angel Shale)
7 create wide valleys. The level of bedrock fracturing, which is also a function of bedrock
8 resistance, affects the frequency of tributary debris fans and deep pools (Howard and
9 Dolan 1981).

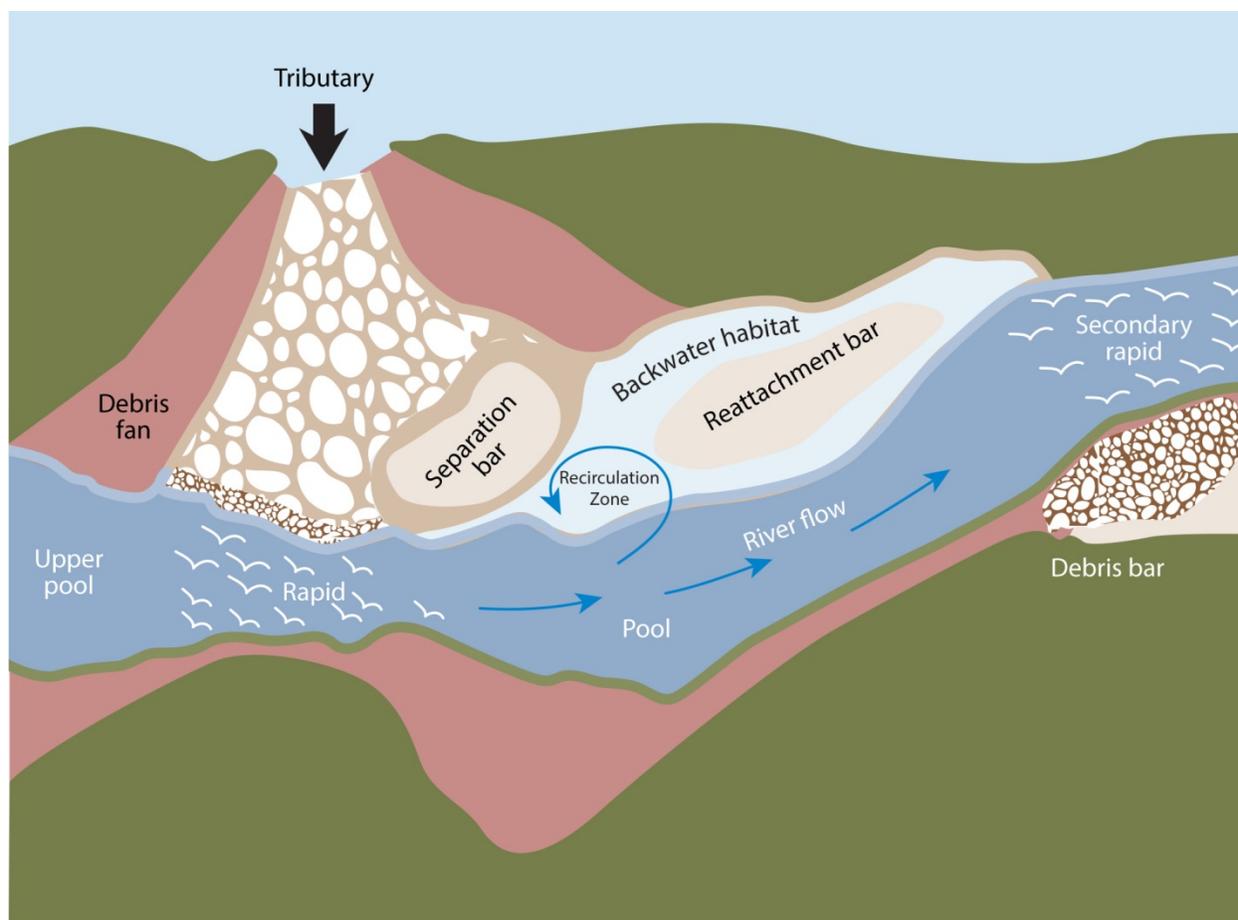
10
11 Schmidt and Graf (1990) defined 11 geomorphic reaches within Marble and Grand
12 Canyons based on parent geologic materials, width-to-depth ratios, slope, and relationship to the
13 confluences with major tributaries. These 11 geomorphic reaches are often described as either
14 narrow or wide reaches based on the width of the canyon in that region. A coarser view of the
15 study area, as used in this DEIS, considers three main sections bounded by Glen Canyon Dam,
16 the Paria River, Little Colorado River, and Lake Mead. Beginning at Glen Canyon Dam, the first
17 portion of the river is the 15-mi stretch that runs downstream through Glen Canyon to just
18 upstream of the Paria River at Lees Ferry (RM 0). Glen Canyon has a substantially different
19 geomorphic structure compared to the reaches farther downstream, and it has a limited sediment
20 supply. The next section of river is the approximately 62-mi stretch that runs through Marble
21 Canyon. This stretch starts at the mouth of the Paria River at Lees Ferry (RM 0) and extends to
22 just upstream of the Little Colorado River (RM 61.5). The sediment load of this reach is
23 dominated by Paria River inputs. The third section runs through the Grand Canyon and
24 comprises the remainder of the river downstream of the Little Colorado River. The sediment load
25 of this third portion is the cumulative supply provided by contributions from the Paria River
26 reach, the Little Colorado River, and various other small tributaries.

27 28 29 **3.3.1.1 Geomorphic Features of the Colorado River**

30 31 32 **Fan-Eddy Complexes**

33
34 The areas along the river where a tributary debris fan partially blocks the flow are
35 commonly referred to as fan-eddy complexes (Schmidt and Rubin 1995; Schmidt et al. 2004).
36 Formed at the mouths of tributary canyons, debris fans are sloping deposits of poorly sorted
37 sediment ranging in size from clays and silts to larger boulders. Deposited by tributary debris
38 flows, debris fans and their associated processes play a significant role in defining the
39 geomorphic characteristics of the Colorado River in Marble and Grand Canyons
40 (Webb et al. 1988; Reclamation 1995; Yanites et al. 2006).

41
42 Debris fans extending into the Colorado River obstruct the channel, making it narrower
43 and raising the bed elevation, which forms rapids (or riffles) through the point of constriction and
44 the downstream-directed current becomes separated from the riverbank (Griffiths et al. 1996)
45 (see Figure 3.3-2). Downstream from the constriction, the channel is typically wider, the main
46 current reattaches to the riverbank, and some of the water is redirected upstream (Schmidt and



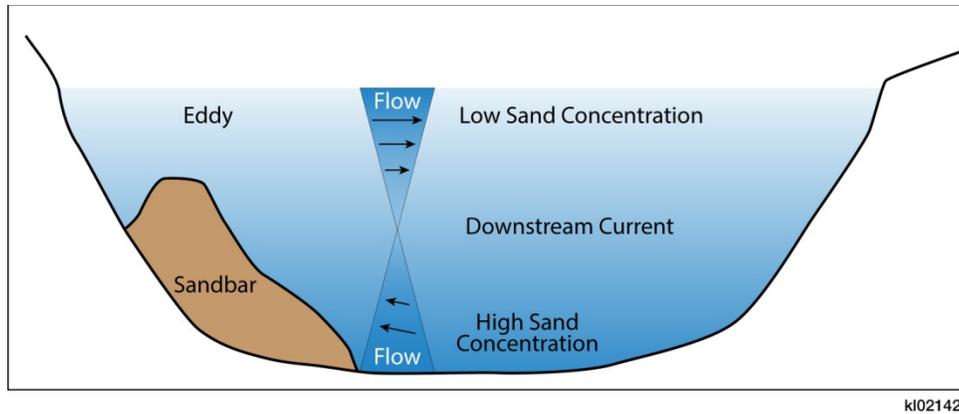
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FIGURE 3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River
(Source: Webb and Griffins 2001)

Graf 1990). This change in flow direction forms a zone of low-velocity recirculating water (i.e., an eddy) between the points of separation and reattachment and between the main channel and riverbank (Rubin et al. 1998). These conditions allow for sediment to become entrained within the recirculation zone where the lower velocities enhance the potential for sediment deposition (Schmidt and Graf 1990; Schmidt and Rubin 1995). Figure 3.3-3 presents a cross-sectional diagram demonstrating how these complexes can trap sediment and work to build sandbars. In this instance, water with relatively high sand concentration (near the streambed) moves toward the eddy and builds a sandbar; water with relatively low sand concentration (near the surface) moves from the eddy back to the main channel (Reclamation 1995).

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



1
2 **FIGURE 3.3-3 River Cross Section Depicting Sediment Entrapment and**
3 **Sandbar Building (Source: Reclamation 1995)**
4
5

6 Nearly all sandbars in Grand Canyon are associated with fan-eddy complexes. In general,
7 these complexes generate consistent sandbar features, which include separation bars and
8 reattachment bars, based on their specific locations within the recirculation zone (Schmidt and
9 Grams 2011a). They continuously exchange sand with the river. Thus, the sandbars commonly
10 found along the banks of the Colorado River are generally dynamic and unstable. Separation bars
11 form along the downstream face of a debris fan, and reattachment bars form outward from the
12 downstream point where the recirculation zone meets the channel bank (see Figure 3.3-2).
13

14 Sandbars form a fundamental element of the river landscape (Figure 3.3-1) and are
15 important for vegetation, riparian habitat for fish and wildlife, cultural resources, and recreation
16 (Wright, Schmidt et al. 2008; Reclamation 1995). For example, they form the substrate for
17 limited riparian vegetation in the arid environment. Low-elevation sandbars create zones of low-
18 velocity aquatic habitat (i.e., backwaters) that may be utilized by juvenile native fish. These low-
19 elevation sandbars are also a source of sand for wind transport that may help protect
20 archaeological resources. In addition, beaches provide recreational value for visitors
21 (e.g., camping areas for river and backcountry users). For recreational use (e.g., camping and
22 boating), visitors generally prefer separation bars over reattachment bars because they are
23 composed of finer grained sand, experience less frequent inundation by rising river levels, and
24 have lower velocity conditions for mooring boats (Reclamation 1995).
25

26 Fan-eddy complexes also produce important ecologic niches in the canyon. For example,
27 stagnant return-current channels within eddies can support riparian vegetation, attract native fish
28 (e.g., humpback chub), and provide stable substrate for other aquatic organisms (e.g., algae)
29 (Schmidt et al. 2007; Webb and Griffiths 2001).
30

31 **High Terraces** 32

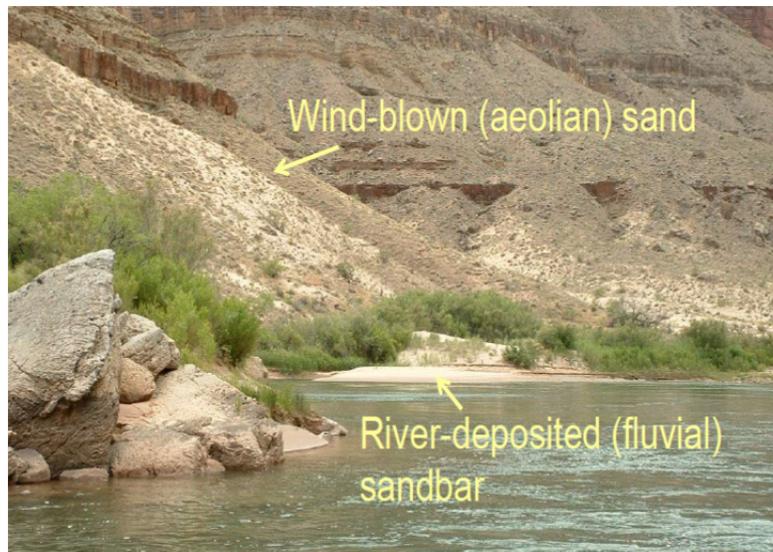
33 High-elevation terraces found in reaches of Glen and Grand Canyon support native
34 vegetation and desert riparian communities and may contain buried or partly buried
35

1 archeological remains. These terraces can be referred to as Holocene terraces because they were
2 formed during the Holocene Epoch (i.e., the time since the last ice age). They were originally
3 formed as sandbars as part of fan-eddy complexes during large natural pre-dam flood events
4 (100,000 cfs and greater). In general, larger flood flows resulted in higher terraces and higher
5 terraces are generally indicative of older deposits (Schmidt and Grams 2011a;
6 Reclamation 1995); however, other factors, such as new large tributary debris flows, can also
7 produce terraces under similar flow conditions.

8
9 Aeolian, or wind-blown, deposits can also occur on high-elevation terraces and on
10 sandbars near the river, as pictured in Figure 3.3-4. These deposits can be classified as either
11 relic (e.g., derived from sediment emplaced in high terraces) or modern (e.g., derived from
12 modern river sandbars) (Draut and Rubin 2008). Relic deposits are largely inactive because of a
13 lack of river sediment replenishment at higher elevations and subsequent colonization by
14 vegetation and biological soil crusts. For modern deposits, activity is largely controlled by
15 prevailing wind direction and the amount of bare sand surface area available on the sandbar.

3.3.1.2 Glen Canyon Geomorphology

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20 The river immediately downstream of Glen Canyon Dam was intentionally scoured in
21 1965 during a series of high-pulse flows, with the intent of raising the elevation of Lake Mead
22 and scouring the reach immediately below the dam in order to increase the efficiency of the
23 powerplant (Topping et al. 2003). During the initial pulse flows, approximately 5.0 million tons
24 of fine sediment were scoured from Glen Canyon between the dam and Lees Ferry over a period
25 of 3 months. Additionally, approximately 17.62 million tons of material were scoured from the
26 reach between Lees Ferry and Grand Canyon gaging stations near Phantom Ranch



27
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31 **FIGURE 3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River (Source: Draut 2012)**

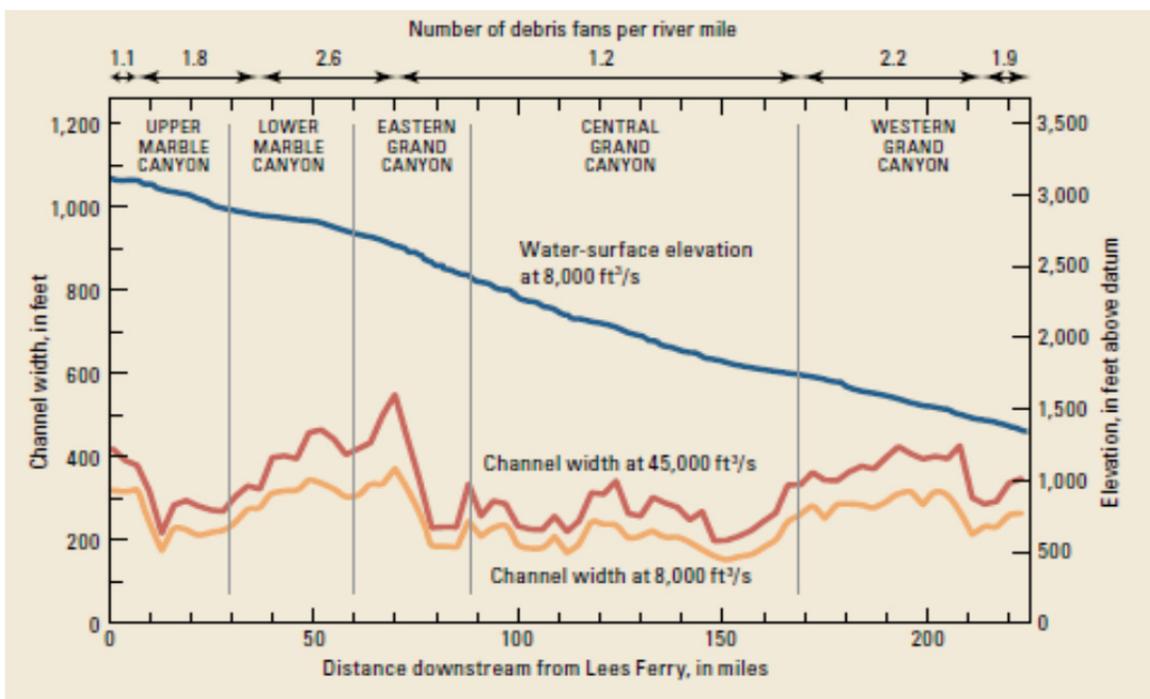
1 (Topping et al. 2003; Wright et al. 2005). These pulse flows, coupled with other dam operation
2 activities, transformed the pre-dam Glen Canyon, which had plentiful sand, native species, and
3 active natural processes, to a present-day Glen Canyon that is incised, narrowed, and armored
4 (Grams et al. 2007).

5
6 Glen Canyon exhibits a low gradient and has few debris-fan deposits and small riffles.
7 The Colorado River through Glen Canyon can be generally characterized as a stable gravel and
8 cobble-bedded channel that is more similar in character to a cold Alpine headwater stream than a
9 lowland desert river (Schmidt and Grams 2011b). For example, the average grain size of bed
10 material has increased from 0.25-mm sand particles in 1956 to gravel particles larger than 20 mm
11 in 1999 (Grams et al. 2007).

12
13 The flow and sediment supply conditions created by the closure and operation of the dam
14 have resulted in bed incision, sediment evacuation, and abandonment to a large degree of any
15 significant sandbar or terrace development in Glen Canyon. Despite this, several large sandbars
16 exist at established recreational sites. The amount of material scoured is equivalent to a
17 cumulative volume about 10.7 million m³, or a 6- to 10-ft drop in channel elevation averaged
18 over the entire reach, ending at the Paria riffle (Schmidt et al. 2004; Wright et al. 2005). This
19 material is not being re-deposited because no major sediment source exists upstream of the Paria
20 River, making sediment a non-renewable resource in modern-day Glen Canyon
21 (Grams et al. 2007). Previously active sandbars, which have been transformed to gravel bars, are
22 also no longer inundated. Based on repeated surveys in Glen Canyon, the channel appears to
23 have adjusted and stabilized to the regulated flow regime, and the rate of erosion has declined
24 since 1984 (Grams et al. 2007). Although the rate of erosion has declined, the remaining pre-dam
25 high-terrace deposits in Glen Canyon are subject to ongoing erosion processes from the Colorado
26 River and ephemeral tributaries (Anderson 2006; Pederson et al. 2011).

27 28 29 **3.3.1.3 Marble and Grand Canyon Geomorphology**

30
31 The longitudinal profile of the river consists of long, flat pool reaches with intermixed
32 short, steep rapids. The water surface elevation of the Colorado River drops from 3,116 ft to
33 1,336 ft over the 226 mi from Lees Ferry to Diamond Creek. However, the majority of this
34 elevation change (between 50 and 66%) occurs through the numerous rapids in less than 10% of
35 the river's length (Leopold 1969; Magirl et al. 2005). The rapids are typically associated with
36 debris-fan deposits formed by tributary debris flows (i.e., fan-eddy complexes described in
37 Section 3.3.1.1), which constrict the channel width, causing an upstream pool formation, steep
38 rapids, and downstream scour hole and pool formation (Dolan et al. 1978; Howard and
39 Dolan 1981; Melis et al. 1995) (Figure 3.3-2). For the Colorado River below Lees Ferry, the
40 locations of debris-fan deposits and rapids, as well as the associated changes in channel width
41 and surface water elevations, have also been quantified (Magirl et al. 2008). Figure 3.3-5 depicts
42 the number of debris fans per RM and the variation in water-surface elevation and channel width
43 for modeled river flows of the Colorado River below Glen Canyon Dam (Schmidt and
44 Grams 2011a).



1

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

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

One of the main resource considerations for sandbars in Marble and Grand Canyon relates to available campsites and campable areas, which is based on considerations of the size, slope, sediment material, and vegetation abundance of a sandbar (see Section 3.11.2 for more details). A comparison of sandbars used as campsites, based on inventories conducted in 1973, 1983, and 1991 (Figure 3.3-6), indicated that the number of campsites increased in both narrow and wide river reaches as a result of a flood in 1983. However, by 1991, erosion reduced the number of campsites to levels closer to the 1973 inventory values. The same study also noted that vegetative overgrowth further reduced the number of campable sites (Kearsley and Warren 1993). According to a study compiled by USGS and cooperating scientists, the open sand area preferred by recreational campers has decreased by 55% since 1998, with an average rate of decline of about 15% per year (Kaplinski et al. 2005).

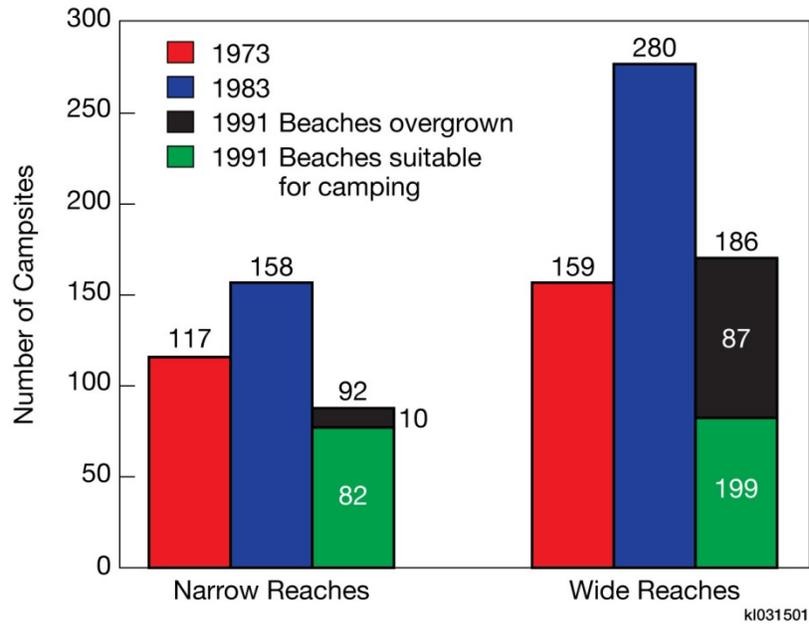


FIGURE 3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted in 1973, 1983, and 1991 (Source: Kearsley and Warren 1993)

Debris fans continue to be replenished and enlarged by debris flows. Thus, the formation of new rapids and the steepening of existing ones will continue in Marble and Grand Canyons. However, it has also been noted that the presence of the Glen Canyon Dam has greatly reduced both the magnitude and frequency of flood flows and, thereby, the capability of the river to move boulders from the rapids (Reclamation 1995). As a result, many debris fans may experience a buildup of boulders and an accumulation of smaller sediment particles (Melis and Webb 1993). Dam releases above powerplant capacity flows can partially rework debris-fan deposits, but this reworking is at a rate that is slower than the aggradation from tributary debris-flow deposits (Yanites et al. 2006).

3.3.2 Sediment Characteristics and Transport Mechanisms

Sediment, especially as it occurs in sandbars along the Colorado River below Glen Canyon Dam, is an important and dynamic resource, and is one of the natural resources addressed by the Grand Canyon Protection Act of 1992. The Grand Canyon Monitoring and Research Center (GCMRC) has been focused on gathering sediment-related data, and understanding of important aspects of sediment science has evolved since the 1995 EIS (Reclamation 1995).

Glen Canyon Dam, completed in 1963, affects stream flow, sand supply, and sand transport in the Colorado River in Glen, Marble, and Grand Canyons. Historically, the Colorado River conveyed high suspended sediment concentrations throughout most seasons and had much

1 larger flood flows and lower base flows (Schmidt and Grams 2011a). Because sediment sources
2 for the Colorado River are not uniformly distributed in the Colorado Plateau, the placement of
3 Glen Canyon Dam effectively cut off approximately 94% of the historical sediment supply from
4 the upper watershed (Andrews 1991; Topping et al. 2000a; Wright et al. 2005). The conditions
5 for sediment replenishment downstream of the dam are now imposed by the tributaries
6 (e.g., Paria River and Little Colorado River), which contribute to the Colorado River
7 downstream of the dam and affect the mechanisms that control sandbars in Glen, Marble, and
8 Grand Canyons. Secondly, the dam has reduced the capacity of the Colorado River to transport
9 sand and other sediment. The natural peak flows that occurred annually prior to dam construction
10 had a tremendous capacity to transport sediment.¹ Maximum releases from the dam are
11 substantially less than those historic annual peak flows. The third major change was the
12 reduction in the high-water zone from the level of pre-dam annual floods down to the level
13 corresponding to managed releases. Thus, the height of annual deposition and erosion of
14 sediment have also been reduced (Reclamation 1995). It has been known for many years that
15 sandbars and sandbar-dependent campsites are being lost. Figure 3.3-7 illustrates the changes
16 that have occurred from 1955 to 2008.

17
18 The sediment resource goal for the LTEMP DEIS is to increase and retain fine sediment
19 volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the
20 elevation of the average base flow for ecological, cultural, and recreational purposes. As a
21 resource, the primary considerations for sediment relate to the spatial and temporal dynamics of
22 sediment storage throughout the Colorado River below Glen Canyon Dam. The focus of this
23 section is the sediment characteristics and transport mechanisms that interact with flow regimes
24 dictated by releases from Glen Canyon Dam to govern erosional and depositional processes
25 affecting sandbars. The processes that generate sandbars are linked to several factors including
26 particle size, sediment supply, flow velocity, channel geomorphology (described previously), and
27 river stage, so it is necessary to consider all these factors when assessing impacts to sediment
28 resources.

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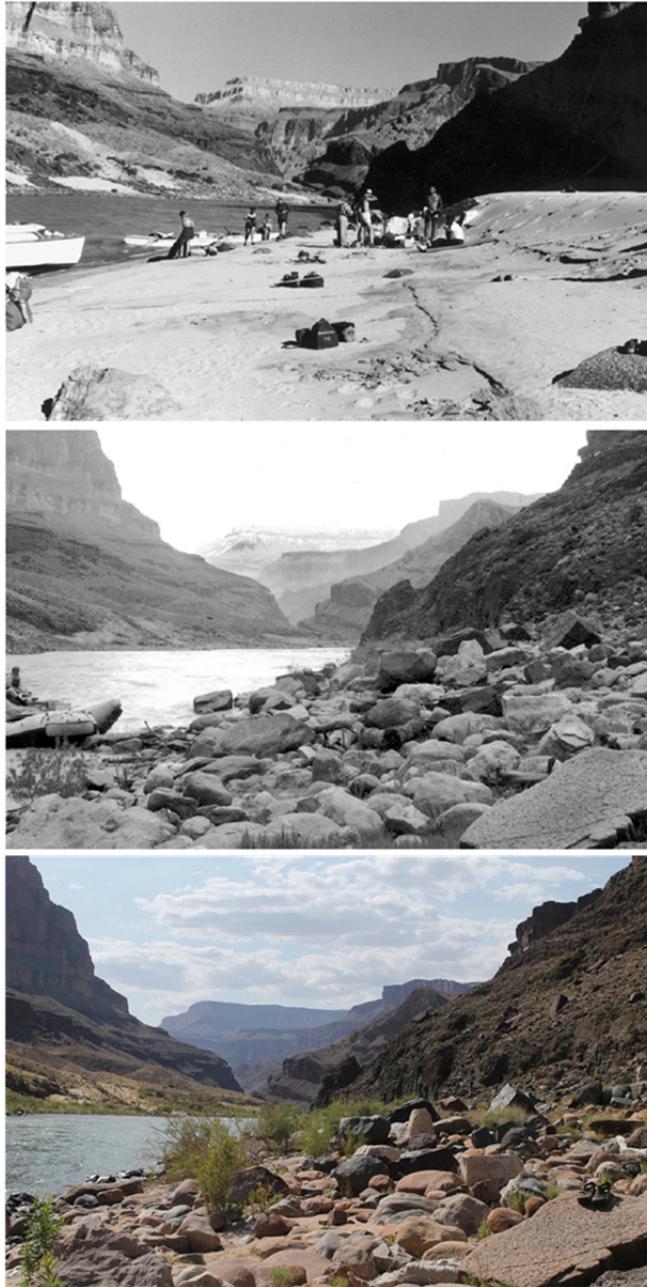
31 **Particle Size and Sediment Supply**

32
33 Sediments are typically classified by particle size, and they include the following classes:

- 34 • Silt and clay (<0.06 mm);
- 35 • Sand (0.06 mm–2.0 mm);
- 36 • Gravel and cobbles (2.0 mm–200 mm); and
- 37 • Boulders (>200 mm).

38
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¹ Sediment transport in the Colorado River was already in decline in the pre-dam era as a result of changes in seasonal rainfall patterns, increased upstream diversions and dam construction, and the slowing of stream entrenchment (Howard and Dolan 1981).



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

1 In general, the term “fine sediment” refers to sediments that are sand-sized or smaller.
2 This group makes up the most abundant sediment size class found along the river, especially in
3 GCNP below the Paria River. GCNRA has little to no fine sediment input and contains mostly
4 coarse sediment until the river reaches its first major tributary, the Paria River. The majority of
5 the sediment delivered to and transported by the Colorado River is defined as silt and clay, which
6 are carried in suspension by most dam releases. The quantity of silt and clay transported depends
7 mainly on tributary supply. Sandbars contain some silt and clay, but their existence primarily
8 depends on the transport of sand.
9

10 Sand is stored throughout Glen and Grand Canyon in bars (or patches) on the riverbed, in
11 eddies, and on terrace sandbars. Sandbars and terraces are used as campsites by boaters and are
12 substrate for vegetation and wildlife habitat. The next-largest sizes are gravel and cobbles,
13 which, together with small boulders, armor the streambed in some places. Certain fish species
14 use shallow gravel beds for spawning. The largest particles are boulders, some larger than
15 automobiles, which fall from the canyon walls or reach the river in debris flows from steep
16 tributary canyons. Boulders create and modify most of the major rapids and are also a factor in
17 the creation of sandbars. Although its riverbed is bedrock in some places, the Colorado River
18 generally is a cobble- and gravel-bed stream through which sand is transported (Graf 1995).
19
20

21 **Flow Velocity**

22
23 The river’s capacity to transport sediment increases exponentially with the amount of
24 water flowing in the river. The turbulence of flowing water is the uplifting force that causes
25 movement of sediment particles. Once the weight of the sediment particles exceeds the
26 suspension force from the water current, the sediment is deposited. The greater the river’s flow,
27 the greater its velocity; the greater the turbulence, the greater its sediment load-carrying capacity.
28 Finer particles (i.e., clay and silt) are carried in suspension by nearly all dam releases. Flows in
29 the river are often large enough to carry sand grains in suspension or roll them along the
30 riverbed, temporarily depositing the grains in areas where water velocity is insufficient to move
31 them. Higher flows and velocities are needed to move gravel and cobbles. The largest boulders
32 remain in place for decades or more, awaiting a flood large enough to move them even short
33 distances along the riverbed.
34

35 The amount of sand stored within the riverbed each year depends on the tributary sand
36 supply (which is highly variable), the pattern of water released from the dam, and the amount of
37 sand already deposited on the riverbed at the beginning of the year. Sand stored on the riverbed
38 is the principal source for building sandbars during periods of high releases.²
39
40

² In an average pre-dam year, sand in Marble Canyon and the upper Grand Canyon would accumulate during 9 months of low flow (July through March); higher flows in April through June (from spring snowmelt) would then erode and transport the stored sand. Since the closure of Glen Canyon Dam, there is no discernible seasonal pattern of accumulation in the canyons (Topping et al. 2000a; Hazel et al. 2006).

1 **River Stage**
2

3 River stage defines the water level associated with a given discharge, which may be a
4 result of both dam release and tributary inflow. Fluctuations in river stage are particularly
5 important to cycles of deposition and erosion within sandbars. While fine sediments are readily
6 transported by the Colorado River, the height of their deposition depends on river stage.
7 Seepage-induced erosion is also affected by fluctuations in river stage because groundwater
8 levels within exposed sandbars rise and fall with increases and decreases in river stage. When the
9 river stage declines faster than groundwater can drain from the sandbar, the exposed bar-face
10 becomes saturated, forming rills that move sand particles toward the river (Reclamation 1995;
11 Alvarez and Schmeckle 2013).
12
13

14 **3.3.2.1 Sediment Sources**
15

16 Sediments in the Colorado River are delivered by tributary streams and ephemeral
17 washes. Although most of the water in the Colorado River originates in the Rocky Mountains,
18 most of its sediment load originates from more arid regions in the interior of the river basin
19 (Schmit and Schmidt 2011). In the post-dam era, the Colorado River is no longer the source of
20 sediment to the river downstream of the dam. As a result of the closure of the Glen Canyon Dam,
21 the annual sediment supply past Lees Ferry dropped from a pre-dam level of around 57 million
22 MT/yr to about 0.24 million MT/yr during the post-dam period from 1966 to 1970, a reduction in
23 sediment supply at Lees Ferry of more than 99% (Topping et al. 2000a).
24

25 The Paria River, Little Colorado River, and nearly 800 smaller gaged and ungaged
26 tributaries now serve as the primary sources of sediment to this reach of the river
27 (Webb et al. 2000; Schmidt and Grams 2011a). Taken together, the contributions of sand from
28 various sources provide the Grand Canyon with approximately 16% of its pre-dam sand levels
29 (Wright et al. 2005). Mass balance sand budgets in the Colorado River below the dam vary
30 within and among years, depending on the amount of tributary sediment input and the monthly
31 volume releases from the dam. Because of this dynamic nature, it is only possible to provide an
32 estimate of the relative sediment budget that is representative of the river channel. In general, the
33 lesser tributaries in the upper Marble Canyon upstream of RM 30 together contribute roughly
34 10% of the amount of sand annually supplied by the Paria River; downstream from RM 30, the
35 lesser tributaries supply negligible amounts of sand (Griffiths and Topping 2015). However, the
36 sediment inputs from these tributaries appear to be decreasing over time (see the following
37 sections for further details related to gaged and ungaged tributary sediment inputs). If this trend
38 continues, then experimental flows (e.g., HFEs, described in more detail below) may be less
39 effective at beach building in the future. Thus, sediment supply is one of the important
40 uncertainties related to managing this resource.
41

42 Debris flows have been documented in nearly 740 tributaries in the Marble and Grand
43 Canyons between Lees Ferry and Diamond Creek; tributaries between the dam and Lees Ferry
44 were found to produce only stream flow (Webb et al. 2000). Debris flows tend to be high-
45 magnitude, short-duration events. Debris flows create and maintain the rapids (i.e., hydraulic

1 controls), control the size and location of eddies, and serve as potential sources of sand to
2 replenish sandbars of the Colorado River in the Marble and Grand Canyons.

3
4 The coarse sediments associated with debris-fan deposits can only be mobilized during
5 flood flows and do not constitute a significant contribution to sediment loads transported by the
6 river. However, their dynamics are important with respect to their retention of fine sediments and
7 the development of geomorphic structures (e.g., fan-eddy complexes). While it has been
8 predicted that the reduction in flood flows caused by Glen Canyon Dam could result in a greater
9 accumulation of coarse sediment on debris fans, it has been shown that flood flows during the
10 post-dam era also have the potential to transport coarse sediments from debris flows and eroding
11 sandbars (Schmidt and Grams 2011a).

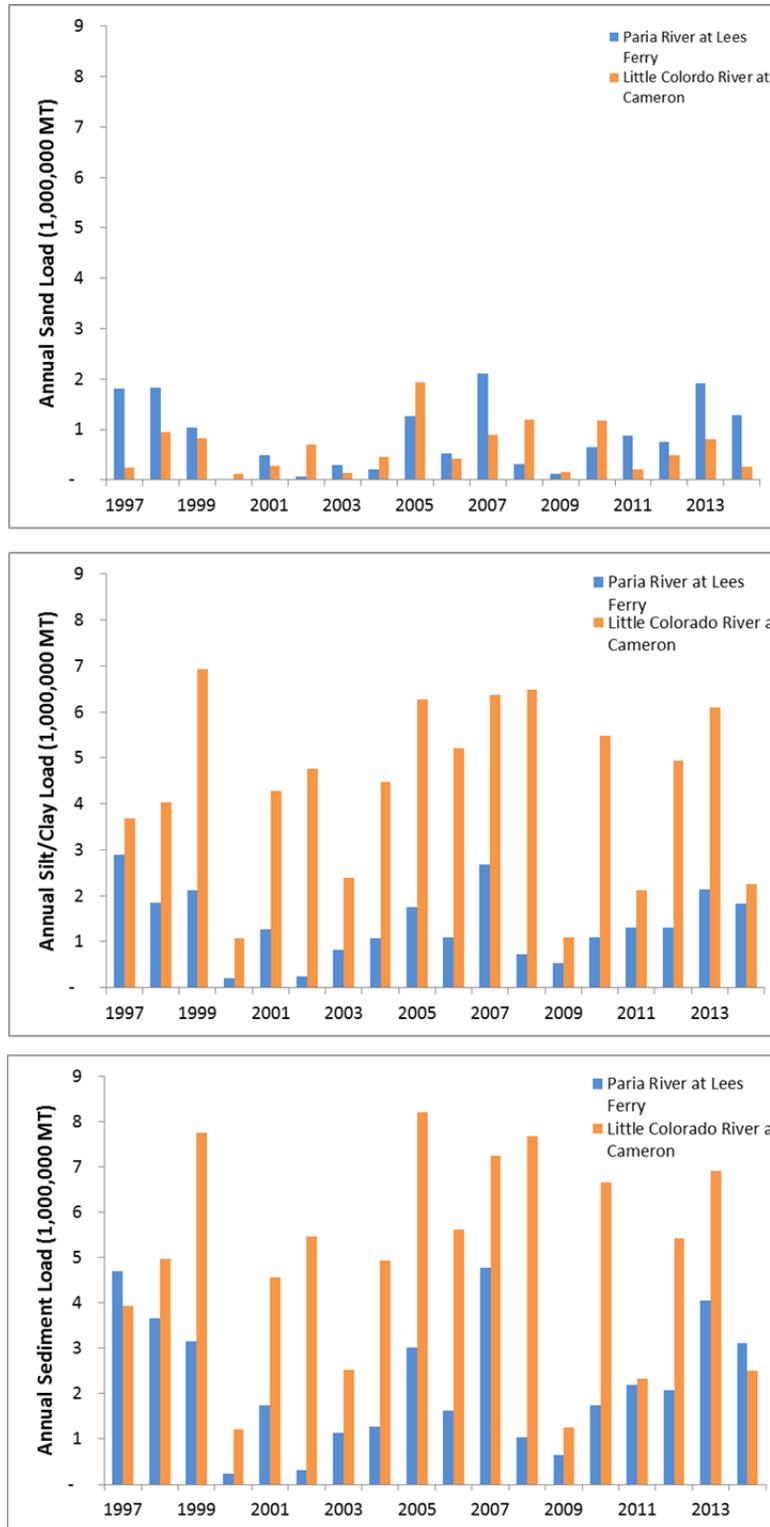
12
13 The occurrence and size of both debris flows and flash floods are influenced by geologic
14 and geomorphic conditions within the watershed (see Section 3.3.1.1 for more detail on the
15 geomorphic features of the Colorado River within the project area). They are also affected by the
16 prior history of flows and the amount and intensity of precipitation. For example, Havasu Creek
17 has not had a debris flow in recent geologic time, but it had an enormously destructive flash
18 flood in September 1990. In general, slope failures in the steep tributary valleys commonly
19 trigger debris flows; however, the geologic conditions favorable for debris flows from side
20 canyons vary greatly throughout the area. Therefore, the potential for sand delivery from these
21 tributaries to the mainstem Colorado River also varies throughout the canyon (Webb et al. 2000).

22 23 24 **Gaged Tributaries**

25
26 The two largest sediment-contributing tributaries to the Colorado River downstream of
27 the Glen Canyon Dam are the Little Colorado River and Paria River. Sand contribution from the
28 Paria and Little Colorado Rivers, estimated at USGS gauging stations, varies greatly from year to
29 year (see Figure 3.3-8). Together, these two tributaries supplied about 10 to 15% of the total sand
30 load in the pre-dam era (Topping et al. 2000a). Today, they are the two principal suppliers of
31 sand to the Colorado River downstream of the dam through the project area.

32
33 The amount of sediment supplied by the Paria River is one of the highest among
34 watersheds on the Colorado Plateau. From 1997 to 2014, the mean annual load has been
35 estimated to be about 2.24 million MT/yr (GCMRC 2015a). Long-term records of sand inputs for
36 the Paria River have suggested that approximately 75% of the average sand supply is delivered
37 during the summer and fall when monsoonal storms are most likely to erode hill slopes in the
38 upper basin and carry more fine sediments (Topping et al. 2010; Wright and Kennedy 2011). The
39 historical median diameter of Paria River sand is approximately 0.13 mm; based on more recent
40 data from 1994 to 2000, about 92% of the influx of sand from the Paria River is finer than
41 0.25 mm (Topping 1997; Hazel et al. 2006).

42
43 The annual average sediment load for the Little Colorado River, using data from 1994
44 and 2009, has been estimated to be about 4.34 million MT/year, of which approximately 30 to
45 40% was sand (GCMRC 2015a). Research from the mid-1980s through the early 2000s showed
46 that the Little Colorado River contributed substantially less sand than the Paria River over a



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

1 decadal time scale, despite the fact that the Little Colorado River basin is nearly 18 times larger
2 than the Paria River basin (Wright et al. 2005; Rubin et al. 2002). These reductions in sediment
3 supply could be related to reduced flooding of the Little Colorado River, water loss (infiltration)
4 in dryland channels in the increasingly arid climate within the Little Colorado River watershed
5 (Block and Redsteer 2011), or the presence of multiple dams along the Little Colorado River.
6
7

8 **Ungaged Tributaries**

9

10 Sediment supplied by the numerous small ungaged tributaries along the Colorado River is
11 much more difficult to estimate because there are no stream gages. Studies have attempted to
12 calculate sediment loads from ungaged tributaries using a number of methods, including mass-
13 balance calculations assuming quasi-equilibrium, regional sediment-yield equations, sediment-
14 rating curves, and peak discharge to total sediment-load relations (Griffiths and Topping 2015).
15 However, there has been some scientific debate over these methods and over the resulting
16 estimates from these various sources (Griffiths and Topping 2015; Schmidt and Grams 2011a).
17 As a result, eight new gages were established in the late 2000s on previously ungaged lesser
18 tributaries in Glen, Marble, and Grand canyons to better estimate the supply of fine sediment
19 (sand, silt, and clay) from these tributaries to the Colorado River (Griffiths and Topping 2015).
20 Over the 13-year study period, the annual sediment load from the lesser tributaries to the
21 Colorado River in upper Marble Canyon was found to vary two orders of magnitude, from
22 approximately 1,800 to 340,000 metric tons of sand and around 2,900 to 370,000 metric tons of
23 silt and clay. This is equivalent to about 10% of the measured mean annual sand load, although
24 the annual sand load of the lesser tributaries as a percent of the Paria River sand load actually
25 ranged from 1.6 to 49% during individual years. The measured mean-annual silt-and-clay load
26 translates to about 8% of that in the Paria River over the same period (Griffiths and
27 Topping 2015).
28

29 Results from the more recent sediment-monitoring network also found that sediment
30 loads do not necessarily correlate with drainage size, and cumulative sediment loads may vary by
31 two orders of magnitude on an annual basis. Thus, previous indirect estimates of annual sediment
32 load from the tributaries were generally too high; this translates to a sediment budget for the
33 Colorado River below Glen Canyon Dam that is in greater deficit than previously concluded by
34 most researchers (Griffiths and Topping 2015).
35
36

37 **3.3.2.2 Sediment Transport and Storage**

38

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

1 variations in sandbar and channel-margin deposits throughout the Colorado River (Schmit and
2 Schmidt 2011).

5 **Sediment Transport**

6
7 The term “sediment load” refers to sediment being transported by the river. Sediment
8 load is further categorized as either bedload (i.e., particles moving along the river bottom) or
9 suspended sediments (i.e., particles in the water column). More than 90% of the sand transported
10 through the Colorado River system is considered suspended load (Schmidt and Grams 2011b).
11 Sediment transport is controlled by a balance of forces (shear stress, drag, buoyancy, and
12 gravity) acting on sediment particles, where the force balance is further controlled by properties
13 of the flow, river geomorphology, and the surface area, concentration, density, size, and shape of
14 the sediment particles available for transport.

15
16 A mass balance approach is commonly used to quantify sediment transport. It is
17 calculated as the mass of sediment that is transported past a specified area over a period of time.
18 Theoretical and empirical formulations that quantify sediment transport are described in more
19 detail in Appendix E.

22 **Sediment Storage**

23
24 Sediment deposits at rest on the riverbed, within sandbars, and along channel margins
25 represent the sediment storage of a river. Sediment storage is the result of coupled flow,
26 sediment transport, and geomorphological conditions (e.g., low-energy recirculating flow within
27 fan-eddy complexes) that result in deposition of sediments. It is important to note that sediment
28 storage does not necessarily mean that there is no movement; instead, it refers to the net
29 condition (i.e., mass balance) between sediment deposition and erosion at a point of interest over
30 a specified period of time. Thus, sediment storage is a dynamic condition that varies based on the
31 specific spatial and temporal scales considered; it can be increasing (net deposition), decreasing
32 (net erosion), or at equilibrium. For example, the net sediment mass balance for a river reach
33 may be in equilibrium over a year-long period. However, on a finer geographic scale, an
34 individual bar may actually be aggrading or eroding as it exchanges sediment with another
35 location within a reach. On a finer temporal scale, seasonal variation over the year-long period
36 would also become apparent.

37
38 It has been estimated that more than 80% of the post-dam fine sediment in the Marble
39 Canyon reach is stored in eddies below the 8,000 cfs stage (Hazel et al. 2006). However,
40 deposition above this stage determines the amount of sand that can be seen and used by visitors
41 to Grand Canyon National Park and how much sand is potentially available for campsites
42 (Schmidt and Grams 2011b). Research has also shown that sand supplied from unregulated
43 tributaries remains in storage for only a few months before most of it is transported downstream,
44 unless flows are below approximately 9,000 cfs (Topping, Rubin et al. 2000; Rubin et al. 2002;
45 Schmidt and Grams 2011b).

High-Flow Experiments

The Glen Canyon Dam Adaptive Management Program (GCDAMP) has conducted six HFEs (the first was called a Beach Habitat Building Flow), which occurred in 1996,⁴ 2004, 2008, 2012, 2013, and 2014, to study the controlling factors that act together to build and maintain sandbars. The primary goal of an HFE is to rework sediments contributed by the Paria River, the Little Colorado River, and ungaged tributaries from the riverbed up to sandbar features that are at elevations above operational flow stages (Schmidt and Grams 2011b; Wright and Kennedy 2011; Reclamation 2011d). The first three HFEs conducted have been extensively studied and reported on (Melis 2011; Melis et al. 2011). Overall, these types of sediment-enriched flows were found to be effective at building sandbars (see Figure 3.3-9 as an example), although post-HFE erosion of sandbars did occur at varying rates depending on flow conditions (Wright and Kennedy 2011). More importantly, the research on these early HFEs highlighted the need to study the cumulative effects of more frequent HFEs and motivated Reclamation to develop an HFE protocol (Reclamation 2011d) that outlines conditions for implementing HFEs. The protocol also provides a methodology for determining the timing, magnitude, and duration of an experimental HFE (Russell and Huang 2010; Reclamation 2011d). The subsequent 2012, 2013, and 2014 HFEs were a direct result of this protocol.

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

Sediment Supply Limitation

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

⁴ Although the purpose of the 1996 HFE was to control nearshore vegetation and remove nonnative fish downstream of Lees Ferry, the experiment also yielded important information on sediment deposition on sandbars (Schmidt and Grams 2011a). It differed in many significant ways from later HFEs including that it was not sediment-triggered and was much longer in duration.

1 Sediment supply limitations can
2 affect the physical processes that govern
3 sediment deposition during HFEs. It is
4 necessary to have a higher concentration of
5 suspended sediments in the main channel
6 to ensure deposition in the fan-eddy
7 complex (Rubin et al. 1998). Conversely,
8 when suspended sediment concentrations
9 are higher in the fan-eddy complex than in
10 the main channel, there exists the potential
11 to erode sand from the fan-eddy complex.
12 During the early stages of an HFE, the
13 finer-grained components are preferentially
14 entrained from the riverbed and
15 transported; consequently, the early
16 sandbar deposits during a high flow are
17 dominated by finer-grained sand. Once the
18 finer-grained sand is winnowed from the
19 riverbed, the suspended sand concentration
20 decreases and the sand in suspension
21 becomes coarser-grained.

22 23 24 **Sandbar Deposition and** 25 **Retention**

26
27 Sandbars experience cycles of
28 deposition and erosion during normal dam
29 operations. Generally, net erosion is a
30 result of turbulent exchange, decreases
31 with distance downstream of the dam, and
32 increase with daily fluctuations in stage.
33 Sandbar erosion can also result from
34 nearshore currents, waves generated by
35 rapids, seepage erosion caused by
36 dewatering sandbars and groundwater
37 flow, wind, tributary floods, and hillslope
38 runoff (Alvarez and Schmeeckle 2013;
39 Schmidt and Grams 2011a;
40 Melis et al. 1995; Budhu and Gobin 1994;
41 Bauer and Schmidt 1993). Sandbar
42 deposition requires high flows and
43 adequate sediment supply. Without
44 occasional periods of sustained high
45 releases (i.e., above powerplant capacity), sandbars, particularly those at high elevation, will
46 eventually erode and not rebuild (Andrews 1991; Schmidt and Grams 2011a).

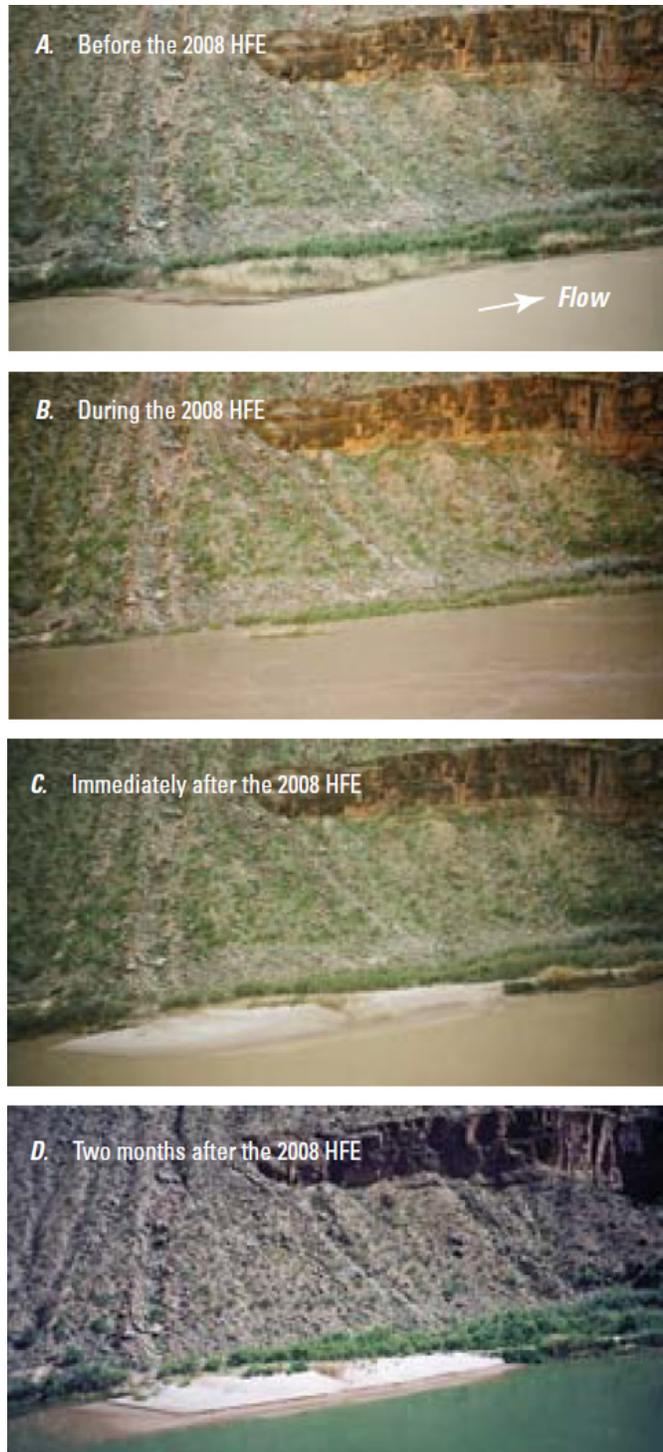
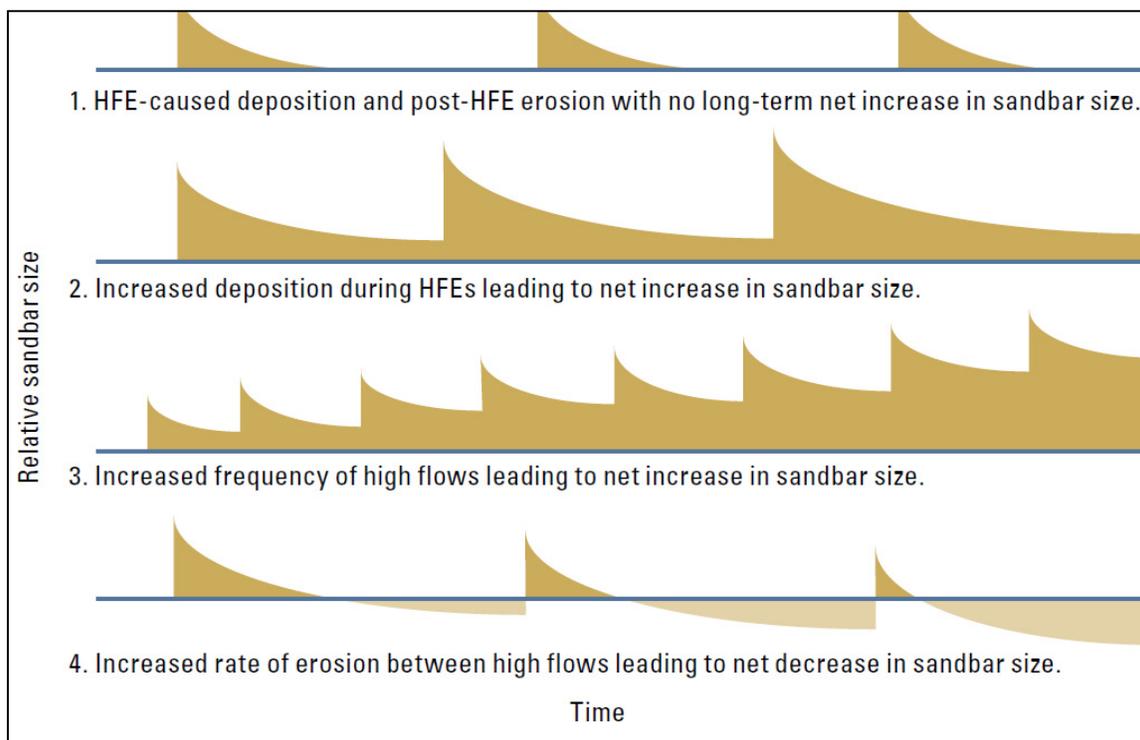


FIGURE 3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to the 2008 HFE (Source: Schmidt and Grams 2011b)

1 Long-term rehabilitation of eddy sandbars can occur only if the increases in sand volume
 2 caused by high flows exceed the erosion that occurs during the intervening periods.
 3 Alternatively, if there are only small amounts of deposition during high flows and large volumes
 4 of erosion during intervening periods, a long-term decrease in sandbar size will result.
 5 Figure 3.3-10 presents a conceptual diagram illustrating the dependency of net sandbar size on
 6 potential variations during a series of hypothetical HFE in the amount of deposition, frequency
 7 of HFEs, and rate of post-HFE erosion. The first graph shows HFE deposition followed by an
 8 equal amount of erosion. The second and third result in net increases in sandbar size by
 9 increasing the amount of deposition during HFEs and increasing the frequency of HFEs,
 10 respectively; this would require sufficiently great antecedent sand enrichment to support either
 11 larger or more frequent HFEs. The last graph depicts a higher rate of erosion following the
 12 HFEs, resulting in net decreases in sandbar size (Schmidt and Grams 2011b).

13
 14 In each of the HFEs,⁵ the majority of sandbars exhibited net deposition, as illustrated by
 15 the data presented in Figure 3.3-11. The highest level of eddy-sandbar deposition above the
 16
 17



18
 19 **FIGURE 3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size,**
 20 **Duration and Frequency of HFEs, and Post-HFE Erosion Rates (Source: Schmidt and**
 21 **Grams 2011b)**

⁵ Summary sandbar results presented are for the 1996, 2004, and 2008 HFEs. The 2012, 2013, and 2014 HFEs post-date the referenced report. Findings from the later HFEs will be released by GCMRC once the research is complete (GCMRC 2014).

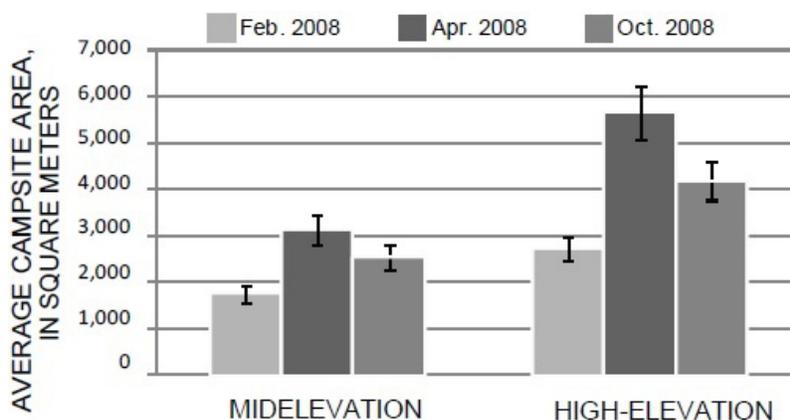


FIGURE 3.3-11 Average Campsite Area above the References Stage: before, after, and 6 Months following the 2008 HFE (Source: Hazel et al. 2010)

reference stage was observed in the parts of Marble and Grand Canyons where the suspended-sand concentration was greatest (Schmidt and Grams 2011b). It is also important to note that, conversely, between 14 and 18% of the monitored sandbars exhibited net erosion (Schmidt and Grams 2011b). Overall, the 1996 HFE resulted in more sandbar erosion than was expected, and antecedent sediment conditions (pre-HFE tributary inputs and analyses of sediment storage) were determined to be limiting with respect to sediment storage in the system. As a result, subsequent HFEs were all performed under more enriched sediment conditions, because it was assumed that increased sand enrichment volumes would yield increased suspended sediment loads and higher volume deposits. However, analysis of data from the 2004 and 2008 HFEs suggested that this assumption was not necessarily true. Greater levels of sand enrichment will lead to greater reach-averaged bed-sand area, but will not always lead to finer reach-averaged bed-sand grain size. Thus, both grain size and magnitude of sand supply need to be considered in order to maximize sandbar deposition (Topping et al. 2010).

In the period after each of the HFEs, sandbars tended to erode. In general, sandbar erosion rates were especially high immediately following each of the HFEs, then continued at a slower rate (Schmidt and Grams 2011b). The pattern of net erosion after the HFEs mirrors the changes that occurred during flooding. That is, the pattern of high-elevation deposition and low-elevation erosion is dominant during high-flow, high-elevation erosion, and low-elevation deposition is the dominant pattern during intervening low flows (Hazel et al. 2006).

Overall, research suggests that the HFEs are effective at temporarily building area and volume of sandbars in fan-eddy complexes. However, long-term rehabilitation of sandbars is only possible if the increases in sand volume caused by the HFEs exceed the erosion during intervening operational flow periods (Schmidt and Grams 2011b) (see Figure 3.3-10). Furthermore, net storage gains in the sandbars as a whole cannot occur if sand is simply being transferred from one bar to another during an HFE. The current state of knowledge obtained from the HFEs does not allow a definitive conclusion that modifying the flow regime alone can

1 increase the area and volume of sandbars over annual or multi-year time scales
2 (Topping et al. 2010).

3.3.2.3 Lake Deltas

6
7 Impounded lakes or reservoirs such as Lake Powell and Lake Mead were designed to
8 provide water storage for a variety of purposes. Their storage capacity is not sustainable,
9 however, because they will become filled with sediment over time (a process known as
10 sedimentation) (Graf et al. 2010). Sedimentation rates among reservoirs are highly variable, due
11 mainly to regional climatic and geomorphic differences that affect sediment delivery. Therefore,
12 reservoir life expectancies are also variable, even among those constructed within the same time
13 period (Graf et al. 2010).

14
15 In general, the coarser particles (i.e., mostly sand) carried into the reservoirs by
16 tributaries are deposited as deltas in the tributaries arm. The majority of finer particles (i.e., silt
17 and clay) are carried farther downstream into the reservoir, where they settle out as lakebed
18 deposits. Deltas fill the upstream parts of the tributary arms first, building toward the submerged
19 mainstem channel and eventually the dam. Some sediment deposited in upstream parts of the
20 delta may be transported downstream as a result of flood flow when the reservoir is low. The
21 upper surfaces of deltas function as important substrate for vegetation and riparian habitat and
22 can affect recreational navigation and the water quality of the reservoir (Reclamation 1995).

23
24 The characteristics of a delta depend on variables such as the quantity and size of
25 inflowing sediment, dam operations, surface water elevation, and hydraulics in the tributary
26 arms. Other factors include erosion and vegetative growth along the margins of the tributary
27 arms and turbulence and density currents in the reservoir. The longitudinal profile of a delta
28 depends primarily on reservoir levels and the slope of the channel through the delta (Strand and
29 Pemberton 1982; Reclamation 1995).

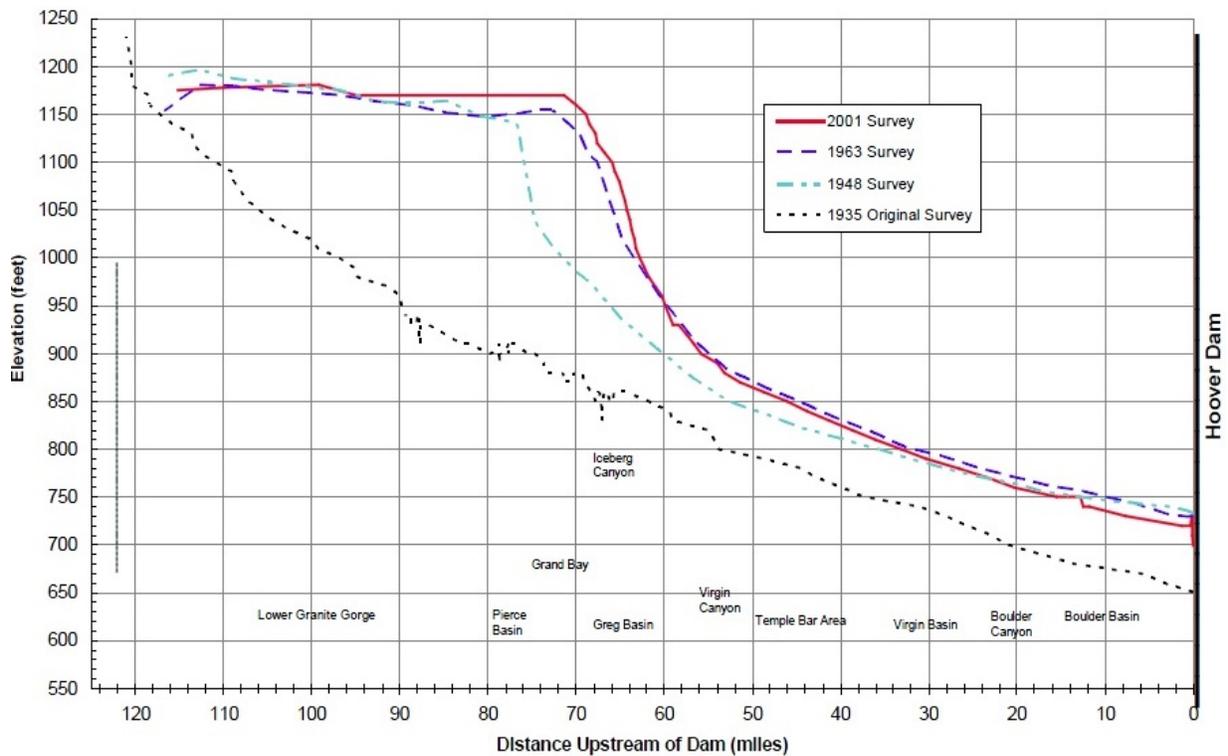
Lake Mead Deltas

30
31
32 The live storage capacity of Lake Mead is 26.399 maf at an elevation of 1,221.4 ft. All
33 sediment transported into Lake Mead by the Colorado River and its tributaries is trapped in
34 deltas and lakebed deposits. Before closure of Glen Canyon Dam, the total upstream drainage
35 area contributing sediment to Lake Mead was 171, 500 mi². Since the dam's closure in 1963,
36 sediment contribution upstream of Lake Powell has been essentially cut off. As a result, the
37 drainage area above Lake Mead has been reduced by an estimated 65%, or approximately
38 59,800 mi² (Ferrari 2008). Additional information on the hydrology and water quality of Lake
39 Mead is presented in Sections 3.2.1.3 and 3.2.2.3, along with a map of the reservoir and vicinity
40 (Figure 3.2-2).

41
42
43
44 Longitudinal profiles of the mainstem Colorado Riverbed elevation upstream of the
45 Hoover Dam in 1935, 1948, 1963, and 2001 are illustrated in Figure 3.3-12. In general, the
46 location along the river where the Colorado River intersects Lake Mead depends greatly on the

1 reservoir's water level elevation, which is primarily controlled by the combination of releases
 2 from the Glen Canyon and Hoover Dams. The maximum recorded riverbed elevation was
 3 1,220 ft, which roughly corresponds to the elevation of the riverbed downstream of Bridge
 4 Canyon (RM 235) in Lower Granite Gorge. Thus, RM 236 is the approximate upper end of the
 5 Colorado River delta, which extends past Pierce basin to about RM 290 (Reclamation 1995).
 6

7 The shape of the Colorado River delta profile is also affected greatly by reservoir
 8 elevation. The delta surface in lower Granite Gorge and upper Lake Mead is relatively flat and
 9 composed mainly of sand, which begins to drop out of suspension at the point where the river
 10 meets the reservoir (as noted above). Beyond the delta, river and reservoir currents can carry
 11 large volumes of finer sediment farther into Lake Mead. Lakebed sediments consist of
 12 predominantly fine sediments: 60% clay, 28% silt, and 12% sand. Lakebed deposits extend all
 13 the way to Hoover Dam at RM 355, even though the longitudinal profile dips steeply at the delta
 14 crest. The elevation of the delta crest, where the slope changes from relatively flat to relatively
 15 steep, has migrated over time (see Figure 3.3-12). According to the 1948–1949 survey of the
 16 delta, the delta crest was at RM 278; by the time of the 1963–1964 survey, it had progressed to
 17 RM 286 (Reclamation 1995). As of 2001, the delta had progressed another 2 to 3 mi lakeward.
 18
 19



20
 21 **FIGURE 3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the**
 22 **Hoover Dam in 1935, 1948, 1963, and 2001 (Source: Ferrari 2008)**
 23
 24
 25

1 **3.4 NATURAL PROCESSES**
2

3 The Colorado River Ecosystem is defined as the Colorado River mainstream corridor and
4 interacting resources in associated riparian and terrace zones, located primarily from the forebay
5 of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam
6 operations impact physical, biological, recreational, cultural, and other resources. An important
7 objective of management of the Colorado River Ecosystem is the ability to sustain healthy
8 populations of native plants and animals and natural ecological processes. NPS management
9 policies state that (1) “whenever possible, natural processes will be relied upon to maintain
10 native plants and animals and influence natural fluctuations in populations of these species” and
11 (2) “the Service ... will try to maintain all components and processes of naturally evolving park
12 ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of
13 the plant and animal species native to those ecosystems” (NPS 2006b). For the LTEMP, the
14 analogous natural processes resource goal is to “restore, to the extent practicable, ecological
15 patterns and processes within their range of natural variability, including the natural abundance,
16 diversity, and genetic and ecological integrity of the plant and animal species native to those
17 ecosystems.” It is not possible to operate Glen Canyon Dam in a manner that could fully restore
18 natural processes and their drivers to those that occurred under unregulated conditions.
19

20 Major drivers of natural processes in river ecosystems below dams are river flow, water
21 temperature, sediment transport, and water quality (including nutrients and turbidity)
22 (Poff et al. 1997; Olden and Naiman 2010; Jones 2013a). These drivers directly and/or indirectly
23 determine the abundance, condition, and status of native and nonnative plants and animals and
24 their habitats in the ecosystem below a dam. The primary effects of dam operations on native
25 plant and animal species and their habitats below the dam are a direct function of (1) the physical
26 conditions (e.g., sediment transport, water temperature) that occur below a dam under specific
27 operations; (2) how those conditions affect habitat quality, quantity, and stability; and (3) how
28 aquatic and terrestrial biota will respond to those changes.
29

30 The construction and operation of Glen Canyon Dam has altered the ecosystem both
31 above and below the dam (e.g., Turner and Karpiscak 1980; Brown and Johnson 1988; Carothers
32 and Brown 1991; Blinn et al. 1992; Gloss and Coggins 2005; Kennedy and Ralston 2011;
33 Cross et al. 2013). Before the dam, the river was sediment rich, transporting large quantities of
34 sediment during spring and early summer and during flood events. Prior to construction of the
35 dam, there was considerable seasonal and annual variability in flow and water temperature.
36 Annual peak discharge typically reached between 85,000 to 120,000 cfs with records of
37 300,000 cfs, while flows in late summer, fall, and winter could be less than 3,000 cfs
38 (Wright et al. 2005; Webb et al. 2005; Vernieu et al. 2005). Water temperatures fluctuated
39 seasonally between 0°C (32°F) and 30°C (86°F), with highest water temperatures occurring in
40 summer.
41

42 The physical changes that have resulted from dam construction and operation include
43 serving as a barrier to the movement of most aquatic organisms between the Upper and Lower
44 Colorado River Basins, a decrease in mean main channel water temperatures, a reduction in
45 sediment supply and transport, increased bed scouring and incision, a reduction in peak flows
46 with coupled reductions in the height of annual sediment deposition and areas of sediment

1 erosion, increased daily fluctuations in flow and stage, and increased water clarity
2 (Reclamation 1995; Topping et al. 2000a, 2003; Grams et al. 2007). Following completion of the
3 dam, operations resulted in lower maximum annual volumes, lower peak flows, higher base
4 flows, and decreased annual flow variability (Vernieu et al. 2005). In addition, in order to
5 increase the value of hydropower, daily fluctuations increased, at times varying from 5,000 to
6 30,000 cfs (Wright et al. 2005). The incoming sediment load is deposited in Lake Powell and
7 water released from the dam is clear. As a consequence, there has been a significant reduction in
8 sediment supply and transport in the main channel below the dam (Topping et al. 2000a;
9 Vernieu et al. 2005; Wright et al. 2005). Because of the location of the penstocks, water released
10 from the dam is cold, averaging about 8°C (46°F), and downstream water temperatures exhibit
11 comparatively little seasonality, ranging from about 9°C (48°F) to 14.4°C (58°F) with highest
12 river temperatures occurring in late fall or early winter (Vernieu et al. 2005).
13

14 The presence of the dam and dam operations has resulted in changes in flow, sediment
15 transport, connectivity, and water temperature. These physical changes, in turn, have resulted in
16 an increase in nonnative riparian vegetation, changes in the distribution and composition of
17 riparian vegetation communities, changes in the aquatic food base, the loss or reduction of native
18 fish, and increases in nonnative fishes (Valdez and Carothers 1998; Gloss and Coggins 2005;
19 Ralston 2005). The physical changes have resulted in a downslope migration of riparian
20 vegetation toward the river's edge (Reclamation 1995), the establishment of marshes in the varial
21 zone (Stevens et al. 1995), the development of a cold-water zone that supports rainbow trout
22 (McKinney, Speas et al. 2001; Reclamation 2011e), changes in the composition and productivity
23 of the aquatic food base (Kennedy and Gloss 2005), and a restriction in the distribution,
24 reproduction, and growth of native fish in locations downstream of the dam and tributaries
25 (Gloss and Coggins 2005).
26

27 The status of physical conditions in the river is described in Section 3.2 (Water
28 Resources) and Section 3.3 (Sediment Resources). These sections describe the past and current
29 conditions associated with hydrology and flow, water quality (including temperature), and
30 sediment transport and storage. Descriptions of biological resources in the system may be found
31 in Sections 3.5.1 (Aquatic Food Base), 3.5.2 (Native Fish), 3.5.3 (Nonnative Fish),
32 3.6 (Vegetation), and 3.7 (Wildlife).
33
34

35 **3.5 AQUATIC ECOLOGY**

36

37 This section presents information on the aquatic ecology of the Colorado River between
38 Glen Canyon Dam and the inflow of Lake Mead. Included are discussions of the aquatic food
39 base (i.e., invertebrates, algae, rooted plants, and organic matter that serve as the base of the food
40 web for fish; Section 3.5.1), native fish (including endangered and other special status species;
41 Section 3.5.2), and nonnative fish (including coldwater and warmwater species; Section 3.5.3).
42 For all of these topics, the effects of dam operations and other factors on these resources are
43 discussed.
44
45

1 **3.5.1 Aquatic Food Base**
2

3 Invertebrates (animals without backbones), algae, rooted plants, and organic matter serve
4 as the aquatic food base for fishes in the Colorado River Ecosystem (Gloss et al. 2005). Although
5 most of this food base is produced within the aquatic system, terrestrial inputs to the Colorado
6 River Ecosystem of organic matter (e.g., leaf litter) and invertebrates also contribute. In turn,
7 instream production of both algae and invertebrates help support terrestrial consumers such as
8 grasshoppers and spiders, insectivorous birds and bats, reptiles, and waterfowl; indirect links
9 include peregrine falcons, belted kingfishers, osprey, great blue herons, and bald eagles, which
10 feed on fishes that consume aquatic food base organisms (Bastow et al. 2002; Baxter et al. 2005;
11 Sabo and Power 2002; Shannon, Kloeppel et al. 2003; Shannon et al. 2004; Stevens and
12 Waring 1986a; Yard et al. 2004). See Section 3.7 of this DEIS for a discussion of riparian and
13 terrestrial wildlife. Flow patterns and temperature (all of which were and continue to be
14 influenced by the presence and changing operations of Glen Canyon Dam) have a major
15 influence on the food base of the Colorado River Ecosystem within the Grand Canyon.
16

17 This section presents an overview of the aquatic food base prior to and following the
18 construction and operation of Glen Canyon Dam. Included in the discussion are invasive aquatic
19 species that have affected or may affect food base organisms of the Colorado River downstream
20 of Glen Canyon Dam. The major groups of aquatic food base organisms include (1) periphyton
21 (e.g., algae and cyanobacteria that live attached to rocks and other surfaces) and rooted aquatic
22 plants, (2) plankton (very small plants [phytoplankton] and animals [zooplankton] that occur in
23 the water column), and (3) macroinvertebrates (i.e., invertebrates that are visible to the naked
24 eye).
25

26 The Zuni believe that macroinvertebrates are underwater species that are not yet ready for
27 this world, and any disturbance to them could have negative consequences. The river's life
28 begins at the headwaters. The river is the umbilical cord to the earth, and through the Zuni
29 religion, prayers, and songs there is also an invisible cord to the Zuni. This statement about
30 underwater species relates to the Zuni history, as Zunis believe that their most ancient ancestors
31 emerged onto this world only when they were ready for emergence; to force an aquatic species to
32 change is to impede the species' natural development and future progress, a violation of Zuni
33 beliefs about the world's natural order.
34

35 As summarized by Wellard Kelly et al. (2013), large dams alter the physical template of
36 rivers by changing flow, temperature, and sediment regimes. Nutrients and sediments are trapped
37 in reservoirs such as Lake Powell rather than being carried downstream (Johnson and
38 Carothers 1987). These changes alter riverine food webs, reduce biodiversity, and often lead to
39 extirpation of native species and facilitation of invasion by nonnative species.
40

41 Prior to the construction of Glen Canyon Dam, the productivity of the Colorado River
42 was extremely low due to scouring by annual floods and high turbidity, although there were
43 productive areas in rapids, riffles, whirlpools, and backwaters (Woodbury 1959). Collections
44 made along the banks of the Colorado River and in tributaries or side canyons included
45 28 species of green algae, 5 species of cyanobacteria, 20 species of diatoms, and 91 species of
46 aquatic insects (e.g., mayflies, dragonflies, true bugs, dobsonflies, caddisflies, aquatic moths,

1 beetles, and true flies). Only 16 insect species were collected from sites along the river
2 (including four species of mayflies and three species of caddisflies), while 77 species were
3 collected from tributaries. Examination of fish stomach contents indicated that organisms derived
4 from tributaries and terrestrial habitats played an important part in the diet of river fishes
5 (Woodbury 1959).
6

7 The combination of altered flows, reduced organic inputs from areas upstream of the
8 dam, decreased turbidity, and an altered thermal regime has led to a shift in the aquatic food base
9 in the Colorado River below Glen Canyon Dam (Benenati et al. 2002; Blinn et al. 1995;
10 Kennedy and Gloss 2005). In general, aquatic invertebrate diversity has declined, while density
11 and biomass have increased (Kennedy and Gloss 2005). The influence of Glen Canyon Dam,
12 coupled with sediment inputs from tributary streams, has resulted in a stair-step decrease in the
13 food base biomass in the Colorado River. In the post-dam period, the 16-mi reach of Glen
14 Canyon accounted for 69% of the algal and 50% of the macroinvertebrate mass collected
15 throughout the 224 mi section of the Colorado River. Sites within Marble and Grand Canyons
16 contributed 18 and 41% and 13 and 9%, respectively, of algal and macroinvertebrate biomass.
17 Food base reductions in reaches downstream of the Paria River result from elevated sediment
18 inputs from tributary streams. The suspended sediments increase turbidity and the deposited
19 sediments alter substrate characteristics (Shannon et al. 1994 2001). Thus, the aquatic food base
20 of the tailwater section (between the dam and the Paria River) and the rest of the mainstem
21 (e.g., between the Paria River and Diamond Creek) are often discussed separately. The Colorado
22 River below the Paria River is seasonally influenced by tributary sediment and organic matter
23 inputs, making them more similar to the pre-dam condition, particularly as distance from the dam
24 increases (Rosi-Marshall et al. 2010).
25

26 Glen Canyon Dam operations have played a significant role in the formation of the varial
27 zone (i.e., the portion of the river bottom that is alternately flooded and dewatered during
28 operations, often on a daily basis). It is not uncommon for portions of the varial zone to be
29 exposed for 12–24 hr under normal dam operations (Leibfried and Blinn 1987). Benthic
30 communities subject to periodic stranding, desiccation, ultraviolet radiation, and winter freezing
31 often have depleted species diversity, density, and/or biomass in the varial zone (Fisher and
32 LaVoy 1972; Hardwick et al. 1992; Blinn et al. 1995; Stevens, Shannon et al. 1997). More
33 detailed information on the effects of dam operations on the aquatic food base is provided in
34 Section 4.5.
35

36 37 **3.5.1.1 Periphyton and Rooted Aquatic Plants** 38

39 Physical factors associated with dam releases that have the greatest influence on tailwater
40 algal communities include (1) daily and seasonal constancy of water temperatures,
41 (2) modifications in nutrient regimes, (3) reduced sediment and increased water clarity,
42 (4) formation of stable armored substrates, (5) fluctuations in water levels that produce daily
43 drying and wetting cycles, and (6) reductions in seasonal flow variability and alterations in the
44 timing or occurrence of extreme flows (Blinn et al. 1998). These conditions allowed ubiquitous
45 *Cladophora glomerata* (a filamentous green algae) to become the dominant algal species below
46 Glen Canyon Dam within 6 years of dam closure in 1963 (Czarnecki et al. 1976; Carothers and

1 Minckley 1981; Blinn et al. 1989, 1998; Stanford and Ward 1991). This species remained
2 dominant until 1995 (Blinn and Cole 1991; Blinn et al. 1995; Benenati et al. 1998). Changes in
3 flow regimes (e.g., repeated episodes of exposure and desiccation of the varial zone) and diluted
4 nutrient concentrations associated with higher reservoir volumes caused the decrease in
5 dominance of *Cladophora* (Benenati et al. 1998, 2000, 2002). Prior to June 1995, *Cladophora*
6 comprised 92% of the phytobenthic community, but it decreased to <50% after that time
7 (Benenati et al. 2000). The aquatic flora is now dominated by miscellaneous algae, macrophytes,
8 and bryophytes (MAMB) including filamentous green algae (mainly *Ulothrix zonata* and
9 *Spirogyra* spp.), the stonewort *Chara contraria*, the aquatic moss *Fontinalis* spp., and the
10 macrophyte *Potamogeton pectinatus*. *Cladophora* is still present, but in much reduced levels,
11 probably due to changes in reservoir and river chemistry and discharge regimes
12 (Benenati et al. 2000; NPS 2005a; Yard and Blinn 2001).

13
14 *Cladophora* occurs along the entire course of the river; however, its abundance decreases
15 downstream (Blinn and Cole 1991; Shannon et al. 1994; Shaver et al. 1997; Stevens,
16 Shannon et al. 1997). This decrease results from high suspended sediment loads contributed from
17 the major perennial tributaries, particularly the Paria River and Little Colorado River
18 (Blinn et al. 1995). Suspended sediments reduce photosynthetic efficiency and scours
19 *Cladophora* from substrates (Blinn et al. 1995).

20
21 *Cladophora* is colonized by a wide variety of diatoms (a group of unicellular or colonial
22 algae) and macroinvertebrates because it can offer protection from predators, food, or a substrate
23 that is anchored against flow disturbance (Dodds and Gudder 1992). Diatoms are the dominant
24 food in the tailwaters of Glen Canyon Dam, but become less important downstream, where
25 bacteria play a more important role in the food web (Blinn et al. 1992). *Cladophora* that becomes
26 detached from the substrate in Glen Canyon is exported downstream where it enters the detrital
27 pathways (Angradi and Kubly 1993, 1994). This drifting energy source supports downstream
28 macroinvertebrate communities dominated by midge and blackfly larvae (Blinn et al. 1999).

29
30 The cyanobacteria *Oscillatoria* is co-dominant with *Cladophora* in Marble Canyon and
31 dominates farther downstream in the Grand Canyon due to its tolerance of exposure to air and
32 lower light levels compared to *Cladophora* (Blinn et al. 1992; Stevens, Shannon et al. 1997).
33 Fewer diatoms occur on *Oscillatoria* compared to *Cladophora* (Shannon et al. 1994). Closely
34 attached (adnate) diatoms dominate those that do occur on *Oscillatoria*, while upright or stalked
35 diatoms dominate those that occur on *Cladophora*. Macroinvertebrates and fishes more easily
36 consume the upright diatoms. While *Oscillatoria* provides cover for burrowing midges and
37 aquatic worms, it has little food value for macroinvertebrates (Blinn et al. 1992). Energy from
38 macroinvertebrate biomass associated with tufts of *Cladophora* is 10 times higher than for
39 *Oscillatoria*. Therefore, replacement of *Cladophora* by *Oscillatoria* indirectly reduces potential
40 energy flow in the Colorado River food web (Shaver et al. 1997).

41
42 Submerged macrophytes collected in the mainstem included horned pondweed
43 (*Zannichellia palustris*), Canadian waterweed (*Elodea canadensis*), Brazilian elodea
44 (*Egeria densa*), pondweed (*Potamogeton* spp.), aquatic moss (*Fontinalis* spp.), and muskgrass
45 (*Chara* spp. [green alga]) (Carothers and Minckley 1981; Valdez and Speas 2007).

46

1 The distribution, ecological importance, and favorable temperature range for select
2 primary producer taxa that occur downstream of Glen Canyon Dam are summarized in Table F-5
3 (Appendix F).
4

6 **3.5.1.2 Plankton**

7

8 Plankton occurring in the Colorado River downstream from Glen Canyon Dam includes
9 both phytoplankton and zooplankton. The phytoplankton population in the Colorado River
10 downstream of the Paria River is diverse, but sparse (numbers never exceeded
11 11,400 organisms/gal), and decreased with distance downstream of Lees Ferry. A total of
12 122 species were identified, with diatoms being dominant. In general, the phytoplankton of the
13 Colorado River is considered relatively unproductive due to a combination of high flow rates,
14 low temperatures, elevated turbidity, and scouring action by rapids and suspended solids, which
15 limit reproduction and survival (Sommerfeld et al. 1976).
16

17 The factors that regulate zooplankton in the Colorado River below Glen Canyon Dam are
18 the distribution and abundance of zooplankton in Lake Powell and operations of the dam
19 (AZGFD 1996; Speas 2000). Low levels of Lake Powell may result in increases in the
20 composition and density of zooplankton downstream as waters are withdrawn from layers closer
21 to the surface (Reclamation 1995). Cole and Kubly (1976) concluded that most zooplankton in
22 the Colorado River originated from Lake Powell or tributaries (primarily Elves Chasm and
23 Tapeats and Diamond Creeks). Mean zooplankton density in the 352 km of the Colorado River
24 downstream of Glen Canyon Dam was 614 individuals/m³ (Benenati et al. 2001).
25

26 It has been reported that backwater areas are localities where zooplankton populations
27 can persist (Haury 1986), and that zooplankton densities in backwaters are significantly higher
28 than those from the main channel (AZGFD 1996). Backwaters were thought to support more
29 zooplankton because they are more stable habitats and may retain nutrients that benefit both
30 phytoplankton and zooplankton (AZGFD 1996). Some production of zooplankton occurs in
31 eddies, backwaters, and other low-velocity areas (AZGFD 1996; Stanford and Ward 1986; Blinn
32 and Cole 1991). However, given that even under stable flows waters in backwaters are recycled
33 1.5 to 3.4 times per day; it seems unlikely that water-column resources such as zooplankton
34 could ever become substantially higher in backwaters than in the mainstem river (Behn et al.
35 2010).
36

37 The temperature requirements for select zooplankton taxa are summarized in Table F-6
38 (Appendix F).
39

41 **3.5.1.3 Macroinvertebrates**

42

43 Temperature and suspended sediment modifications immediately below Glen Canyon
44 Dam has resulted in a food base with low species diversity but high productivity that contains a
45 mixture of native and nonnative species. The abundant aquatic macroinvertebrates at Lees Ferry
46 include *Gammarus lacustris* (an introduced nonnative amphipod), midges, snails (*Physella* sp.

1 and *Fossaria obrussa*), and segmented worms (especially Lumbricidae and Lumbriculidae),
2 which are associated with *Cladophora* beds, as well as ooze- and gravel-dwelling worms
3 (Naididae and Tubificidae), fingernail clams in the family Sphaeriidae (*Pisidium variable* and
4 *P. walkeri*), and the planarian *Dugesia* spp. (Blinn et al. 1992; Stevens, Shannon et al. 1997).
5 Prior to 1998, gastropods (snails) were infrequent but have since increased in abundance due to
6 invasion by the nonnative New Zealand mudsnail (*Potamopyrgus antipodarum*) (Valdez and
7 Speas 2007). This species is discussed later in this section.
8

9 Glen Canyon Dam limits the downstream transport of terrestrial materials such as insects,
10 leaf litter, and woody debris. This reduction of organic input, coupled with low temperature
11 variability and highly variable discharges, can contribute to decreased biodiversity and density of
12 macroinvertebrates (Purdy 2005), particularly within the Glen Canyon reach. Seasonal turbidity
13 increases, particularly from the confluence of the Paria River to Lake Mead, also adversely
14 impact macroinvertebrates. The decrease in light penetration lowers primary production and
15 favors the growth of the less nutritious cyanobacteria *Oscillatoria* in the lower reaches of the
16 Colorado River (Blinn et al. 1999). Macroinvertebrates are not generally associated with
17 *Oscillatoria* because it is very compact, has little surface area for colonization, and largely lacks
18 epiphytic diatoms (Blinn et al. 1995).
19

20 In contrast to insects, *Gammarus* and other non-insect macroinvertebrates can complete
21 their development over a relatively wide temperature range (Vinson 2001). *Gammarus* is largely
22 replaced by midges and blackflies below the Paria River (Blinn et al. 1992; Zahn-Seeger, 2010;
23 Donner 2011). The decrease in standing stock of *Gammarus* with distance from Glen Canyon
24 Dam (Blinn and Cole 1991; Blinn et al. 1992) corresponds to a decrease in *Cladophora* biomass
25 and associated epiphytic diatoms downriver (Hardwick et al. 1992). Although blackflies and
26 midges are relatively less prevalent in Glen Canyon, they support more than half of the rainbow
27 trout (*Oncorhynchus mykiss*) production in that reach (Cross et al. 2011). The 2008 HFE caused
28 a 60% decline in overall invertebrate production that was driven by a large reduction in the
29 production of nonnative New Zealand mudsnails (Cross et al. 2011). However, the production of
30 midges and blackflies increased by 30 and 200%, respectively, in the year following the HFE,
31 and these insects supported a 200% increase in rainbow trout production (Cross et al. 2011).
32

33 The relatively high densities of blackfly larvae in the downstream reaches of the
34 Colorado River suggest the presence of smaller food particles (e.g., bacteria) in these reaches
35 (Blinn et al. 1992). Being filter feeders, blackflies are more common in high-velocity areas with
36 little algal cover, including hard, smooth substrates and driftwood lodged among rocks. Limited
37 data suggests that the blackfly assemblage in the river has changed from at least a five-species
38 assemblage to a near monoculture of *Simulium arcticum* (Blinn et al. 1992).
39

40 The Colorado River in Glen and Grand Canyons supports very few mayflies, stoneflies,
41 or caddisflies, probably because cold hypolimnetic releases limit maximum summer warming to
42 62.8°F (Stevens, Shannon et al. 1997). Cold water does not allow successful recruitment of these
43 orders from warmer tributaries (Oberlin et al. 1999). The caddisfly *Ceratopsyche oslari* occurs
44 throughout the Colorado River but at a low abundance (Blinn and Ruitter 2009). Haden et al.
45 (1999) believe that interspecific interactions between *Gammarus* and the net-building *C. oslari*
46 may contribute to the caddisfly's limited occurrence in the Colorado River below Glen Canyon

1 Dam. Since 1994, recent colonizers (possibly as a result of reduced discharge variability from
2 Glen Canyon Dam) throughout the river include caddisflies (*Hydroptila arctica*,
3 *Rhyacophila* spp., *C. oslari*, and others), true flies (*Bibiocephala grandis* and
4 *Wiedemannia* spp.), mayflies (*Baetis* spp.), beetles (*Microcyloepus* spp.), planarians, and water
5 mites (Shannon et al. 2001). However, caddisflies and mayflies remain relatively sparse in the
6 Colorado River, especially upstream of the Paria River. Tables F-2 through F-4 (Appendix F)
7 present the biomass, production, and abundance of invertebrates, respectively, over the course of
8 3 years at various locations in the Colorado River.

9
10 Flow fluctuations and repeated inundation and exposure can have a significant impact on
11 food base organisms in the varial zone. Warm air temperatures in summer or subfreezing air
12 temperatures in winter can cause mortality of macroinvertebrates stranded in the varial zone
13 (Gislason 1985). The varial zone probably provides poor habitat for species with multiple life
14 history stages (Jones 2013b). A typical problem in rivers that experience fluctuating discharges
15 can be a dewatering of areas where adult aquatic insects either emerge or deposit eggs
16 (Vinson 2001).

17
18 Drifting macroinvertebrates, particularly blackflies and midges, are an important food
19 resource for rainbow trout (McKinney and Persons 1999) and other fishes. Flow regime,
20 discharge, and distance from the dam influence drift of macroinvertebrates in the Colorado River
21 (Shannon et al. 1996; Stevens et al. 1998; Sublette et al. 1998). In general, a positive correlation
22 exists between stream drift and flow magnitude; however, reduced flow can increase stream drift
23 through behavioral factors such as crowding and avoidance of desiccation (Blinn et al. 1995).
24 Tributary and terrestrial insects comprise a small portion of the stream drift in the Colorado
25 River corridor (Shannon et al. 1996), even though Minckley (1991) reported that terrestrial
26 insects are commonly found in stomachs of humpback chub (*Gila cypha*). It is possible that
27 terrestrial invertebrate drift is highly punctuated during and immediately after rainstorms and is
28 therefore a rare but locally important resource for mainstem Colorado River fishes
29 (Shannon et al. 1996).

30
31 Table F-7 (Appendix F) summarizes information on the distribution, importance to higher
32 trophic levels, and temperature range for common macroinvertebrates that occur downstream of
33 Glen Canyon Dam.

34 35 36 **3.5.1.4 Nonnative Invasive Species**

37
38 Some nonnative species have been introduced to supplement the aquatic food base.
39 Because of the low benthic food base noted in the late 1960s, Arizona Game and Fish
40 Department (AZGFD) biologists introduced macroinvertebrates into the Glen Canyon reach
41 including crayfish, snails, damselflies, caddisflies, crane flies, midges, true bugs, beetles, and
42 leeches (McKinney and Persons 1999). These introductions were not monitored for a sufficient
43 length of time to determine their success; however, most of these taxa did not persist in the river
44 (Carothers and Minckley 1981; Blinn et al. 1992). *Gammarus lacustris* was also introduced into
45 the Glen Canyon reach in 1968 to provide food for native and nonnative fishes

1 (Ayers et al. 1998). *Gammarus* and midges have become important components of the aquatic
2 food base.

3
4 Other nonnative invasive species that have potentially detrimental effects on both the
5 food base and fish communities have become established in the Colorado River below Glen
6 Canyon Dam. New Zealand mudsnail was first detected in Glen Canyon in 1995. By 1997,
7 densities on cobble/gravel substrates reached about 3,390/ft². Densities averaged 5,567/ft²
8 between 1997 and 2006, except for 2000, when densities averaged 20,540/ft². High densities that
9 year coincided with experimental steady flows. Although the New Zealand mudsnail can
10 withstand short periods of desiccation, its density is generally higher in systems with constant
11 flows (see Section F.2.1.3 of Appendix F). The New Zealand mudsnail has dispersed
12 downstream through Grand Canyon, and was documented in Lake Mead in 2009
13 (Sorensen 2010). The mudsnail accounted for 20 to 100% of the macroinvertebrate biomass at
14 six cobble bars studied in the Colorado River. The snails probably consume the majority of the
15 available epiphytic diatom assemblage. The New Zealand mudsnail is a trophic dead-end and has
16 adversely affected the food base in the Colorado River (Shannon, Benenati et al. 2003).
17 Epiphytic diatom biomass estimates at Lees Ferry were an order of magnitude lower in 2002
18 compared to 1992 (before New Zealand mudsnails were present) (Benenati et al. 1998;
19 Shannon, Benenati et al. 2003). However, the biomass of other dominant aquatic food base taxa
20 has been variable and not apparently influenced by the presence of the snails (Cross et al. 2010).
21 However, at high population levels (e.g., $\geq 9,300$ individuals/ft²), New Zealand mudsnails can
22 substantially modify lower trophic levels (Hall et al. 2006).

23
24 The New Zealand mudsnail can directly affect native species by consuming a large
25 proportion of the primary production (especially periphyton), competing with native snails and
26 other grazing invertebrates, and negatively impacting both invertebrates and vertebrates at higher
27 trophic levels in aquatic food webs that depend on the aquatic invertebrate food base
28 (Riley et al. 2008; Hall et al. 2003, 2006; Vinson and Baker 2008). At high densities, the
29 New Zealand mudsnail may compete with other macroinvertebrates for food (e.g., diatoms) or
30 space (Kerans et al. 2005). Hall et al. (2006) suggest that the New Zealand mudsnail is
31 sequestering a large fraction of the carbon available for invertebrate production and altering food
32 web function.

33
34 The New Zealand mudsnail has a good chance of being transported by either biological
35 or physical vectors because of its small size and locally high population density (Haynes and
36 Taylor 1984). Recreational fishing and fish stocking have been implicated in the spread and
37 introduction of the New Zealand mudsnail (Moffitt and James 2012). The New Zealand mudsnail
38 can also be carried by waterfowl from one system to another and by fish within a system
39 (Haynes et al. 1985).

40
41 In a study to evaluate the ability of rainbow trout to assimilate New Zealand mudsnails, it
42 was found that juvenile rainbow trout will readily ingest the snails but receive little nutritional
43 value from them because the snails have an operculum that protects them from digestive agents.
44 Also, trout lack pharyngeal teeth that would assist in grinding snail shells. Trout fed mudsnails
45 lost 0.14 to 0.48%/d of their initial body weight, while those fed amphipods gained 0.64 to
46 1.34%/d of their initial body weight. Only 15% of New Zealand mudsnails were assumed to have

1 been digested, 32% were dead but present in their shells and assumed to be undigested, and 53%
2 were alive. The results confirm that North American trout fisheries face potential negative
3 impacts from the New Zealand mudsnail invasion (Vinson and Baker 2008). Although the New
4 Zealand mudsnail occurs throughout the river from the Glen Canyon Dam to Lake Mead, its
5 densities tend to be much higher in the upper reaches of the river. For example, in the upper
6 110 km of the river, densities tended to be over an order of magnitude higher than in the
7 remaining 250 km sampled by Vinson and Baker 2008).

8
9 A few nonnative invasive invertebrates are fish parasites that use food base organisms as
10 an intermediate host. For example, the internal parasite *Myxobolus cerebralis*, which causes
11 whirling disease in salmonids, uses the oligochaete worm *Tubifex tubifex* as an intermediate host
12 (see Section 3.5.3.1 for additional information on whirling disease). The parasitic trout nematode
13 (*Truttaedacnitis truttae*) is present in rainbow trout in the Glen Canyon reach. The ecological
14 impact of the infestation is poorly known, but may influence food consumption, impair
15 growth, and reduce reproductive potential and survival of rainbow trout. The nematode may
16 require an intermediate host such as a copepod or other zooplankton taxa (McKinney,
17 Robinson et al. 2001).

18
19 The Asian tapeworm (*Bothriocephalus acheilognathi*) was first introduced into the
20 United States with imported grass carp (*Ctenopharyngodon idella*) and was discovered in the
21 Little Colorado River by 1990. It now parasitizes the humpback chub population from the
22 Colorado and Little Colorado Rivers. The tapeworm could infect all species of native and
23 nonnative fish species in the Little Colorado River (USGS 2004). Cyclopid copepods are
24 intermediate hosts for the tapeworm; however, fish that prey upon small infected fish can acquire
25 tapeworm infections as well. Thus, large humpback chub that normally consume little
26 zooplankton can become infected by preying upon smaller infected fish (USGS 2004).

27
28 Asian tapeworms were recovered in all fish species sampled from the Little Colorado
29 River but were rare in suckers, rainbow trout, and catfish (mean ≤ 0.08 /fish). Their highest
30 abundance and prevalence were in humpback chub (mean 18.36/fish with 84% of fish infected).
31 The abundance and prevalence of the tapeworm in nonnative cyprinids, such as the fathead
32 minnow (*Pimephales promelas*—mean 0.84/fish, with 23% of fish infected), red shiner (*Notropis*
33 *lutrensis*—mean 1.2/fish, with 63% of fish infected), and common carp (*Cyprinus carpio*—mean
34 3.5/fish, with 52% of fish infected), as well as the plains killifish (*Fundulus zebrinus*—mean
35 1.26/fish, with 15% of fish infected), implicates any of these species as being potential hosts that
36 introduced the tapeworm into the Little Colorado River. It is also possible that bait bucket
37 transfers into the upper reaches of the Little Colorado River or into the Colorado River may have
38 been responsible for the introductions (Choudhury et al. 2004).

39
40 Increased body loads of the parasitic copepod known as anchor worm (*Lernaea*
41 *cyprinacea*) and the Asian tapeworm cause poorer body condition in humpback chub from the
42 Little Colorado River. For fishes collected from 1996 to 1999, prevalence of the anchor worm
43 was found to be 23.9%, and the mean intensity was 1.73/fish in the Little Colorado River
44 compared to 3.2% and 1.0/fish in the Colorado River. The prevalence of Asian tapeworm was
45 51.0% and 252/fish in the Little Colorado River, but only 15.8% and 12/fish in the Colorado
46 River. Differences in parasite density and abundance between the Little Colorado River and

1 Colorado River are caused by temperature differences. Temperatures in the Colorado River near
2 the Little Colorado River do not reach those necessary for either parasite to complete its life
3 cycle; thus, these parasites were probably contracted while the humpback chub was in the Little
4 Colorado River (Hoffnagle et al. 2006). Table F-8 (Appendix F) presents the temperature
5 requirements for the Asian tapeworm, anchor worm, and the trout nematode.
6

7 Table F-8 (Appendix F) summarizes information on the temperature requirements for the
8 Asian tapeworm, anchor worm, and trout nematode. While not included in the table, whirling
9 disease infection prevalence and severity in salmonids is greatest at 10 to 15°C (Steinbach Elwell
10 et al. 2009).
11

12 There are concerns about the potential for other nonnative invasive species to become
13 established in the future and further impact the condition of the aquatic food base. The quagga
14 mussel (*Dreissena bugensis*) is one species of particular concern. It can alter food webs by
15 filtering phytoplankton and suspended particulates (Benson et al. 2013). Although there was
16 conflicting information as to the presence of quagga mussels in Lake Powell for a few years prior
17 to 2012, a noticeable population had not yet developed in that year (NPS 2012c). However, as of
18 2014, thousands of adult quagga mussels have been observed within the reservoir on canyon
19 walls, the Glen Canyon Dam, boats, and other underwater structures (Repanshek 2014). Quagga
20 mussels established in Lake Powell may cause changes in dissolved nutrients, phytoplankton,
21 and zooplankton within the reservoir, which would likely impact food web structure or trophic
22 linkages below Glen Canyon Dam (Nalepa 2010). The quagga mussel was first detected in the
23 Colorado River below Glen Canyon Dam in 2014 after it began to establish in Lake Powell.
24

25 As the population of quagga mussels develops in Lake Powell, the potential for mussel
26 larvae to travel through Glen Canyon Dam increases. Those that survive could attach in low flow
27 areas of the Colorado River, but it is not known if they could reach high numbers (NPS 2012c).
28 The risk of the quagga becoming established within the Colorado River Ecosystem is low, except
29 in the Glen Canyon reach, where lower suspended sediment and higher nutrient levels (compared
30 to downstream reaches) favor its establishment (Kennedy 2007). It is unlikely to establish at high
31 densities within the river or its tributaries because of high suspended sediment, high ratios of
32 suspended inorganic/organic material, and high water velocities, all of which interfere with the
33 ability of the quagga mussel to effectively filter food. High concentrations of sand may cause
34 abrasion and physically damage its feeding structures (Kennedy 2007). In addition, it only takes
35 5 days for water to travel from Glen Canyon Dam to Diamond Creek (Kennedy 2007), so few
36 quagga mussel larvae exported from Lake Powell will be large enough (i.e., >0.2 mm) to
37 colonize the mainstem before they reach Lake Mead, where there is already an established
38 quagga population. Larval mortality in the rapids of Grand Canyon also is likely to be high
39 (Kennedy 2007). Quagga mussels are being found in the river below the dam in relatively low
40 numbers; one mussel has been reported from as far downstream as River Mile 209.
41

42 If the quagga mussel obtained moderate densities in Lees Ferry, estimates of filtration
43 capacity indicate they are unlikely to substantially alter the quality (e.g., nutrient concentrations,
44 suspended organic matter concentrations) of water within or exported from Lees Ferry
45 (Kennedy 2007).
46
47

3.5.1.5 Food Web Dynamics

Primary production, specifically diatoms, forms the base of the aquatic food web in Glen Canyon. In contrast, a combination of primary production and terrestrial and tributary inputs of organic matter is the basis of the aquatic food web in Marble and Grand Canyons, but high quality algal matter supports the food web to an extent that is disproportionate to its availability. Midges and blackflies principally fuel the production of native and nonnative fishes, and fish production throughout the river appears to be limited by the availability of high quality prey, particularly midges and blackflies, and fish may exert top-down control on their prey (Carlisle et al. 2012).

The food web within Glen Canyon is rather simple. Complexity increases with distance from the dam (Figures G-2 and G-3 in Appendix G) (Cross et al. 2013). The New Zealand mudsnail and nonnative rainbow trout dominate the food web in the Glen Canyon reach of the Colorado River. The simple structure of this food web has a few dominant energy pathways (diatoms to a few invertebrate taxa to rainbow trout) and large energy inefficiencies (i.e., <20% of invertebrate production consumed by fishes). Epiphytic diatoms, *Gammarus*, midges, and blackflies provide the primary food base for rainbow trout (Cross et al. 2013).

Below large tributaries, invertebrate production declines about 18 fold, while fish production remains similar to upstream sites. However, sites below large tributaries have increasingly diverse and detritus-based food webs. Midges and blackflies are the dominant invertebrates consumed in downstream reaches (Cross et al. 2013). Fish populations are food-limited throughout most of the mainstem, and tend to consume all of the available invertebrate production in downstream reaches (Cross et al. 2013).

3.5.2 Native Fish

Human activities have greatly affected the fish fauna of the Colorado River between Glen Canyon Dam and Lake Mead. Warmwater nonnative fish were introduced as early as the late 1880s (Carothers and Brown 1991). Overall, the Colorado River Basin once contained a unique assemblage of 35 native fish species, 74% of which were endemic (Minckley 1991). Relatively little information is available regarding the fish community prior to the construction of Glen Canyon Dam. Limited sampling in Glen Canyon before dam construction (conducted from 1957 to 1959) reported only two species from the mainstem proper: the nonnative channel catfish (*Ictalurus punctatus*; about 90% of the captures) and the native flannelmouth sucker (*Catostomus latipinnis*; about 10% of the catch) (Woodbury et al. 1959; McDonald and Dotson 1960). In contrast, mainstem backwaters and tributaries of the Colorado River within the Glen Canyon reach had a more diverse fish community, with 14 nonnative and 6 native species, dominated by the native flannelmouth sucker and speckled dace (*Rhinichthys osculus*).

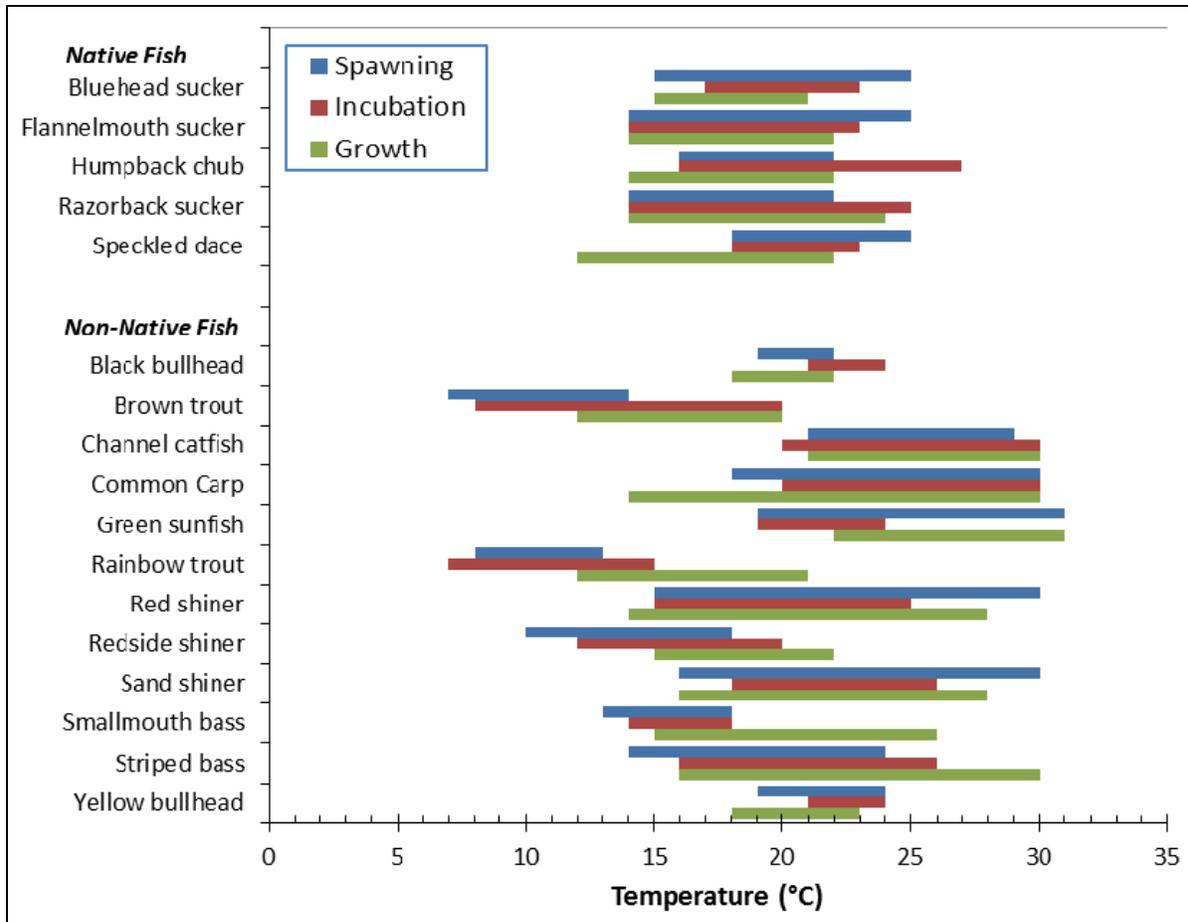
Prior to Glen Canyon Dam closure in 1963, the river carried high sediment loads and, depending on season, flows and water temperatures varied widely (see Section 3.3.3). Construction and closure of Glen Canyon Dam permanently altered the river downstream, creating a relatively clear river with nearly constant year-round cold temperatures

1 (<12°C [54°F]) and daily fluctuating but seasonally modulated flows based on tributary inflows
2 and water storage and electrical generation needs (Reclamation 1995; NPS and GCNP 2013). As
3 a consequence, the cold water temperatures in many miles of the main channel are below those
4 needed for spawning, egg incubation, and growth of most native fish (Figure 3.5-1), and
5 successful reproduction has been largely supported in tributaries (Reclamation 1995). In recent
6 years, however, there has been some newly documented reproduction of native fish in portions of
7 the lower Grand Canyon; adult and larval razorback suckers have been captured there (Bunch,
8 Makinster et al. 2012; Bunch, Osterhoudt et al. 2012; Albrecht et al. 2014; Rogowski and
9 Wolters 2014; Rogowski, Wolters et al. 2015). Colorado River tributaries continue to exhibit
10 natural flow and temperature regimes conducive to native fish spawning and rearing. Most native
11 fish in the mainstem from the dam to the Little Colorado River are large juveniles and adults,
12 while earlier life stages rely extensively on more protected and warmer near-shore habitats,
13 primarily backwaters (Johnstone and Lauretta 2007; Ackerman 2008). The habitats and
14 reproduction of native species in the system are discussed in more detail in later sections.

15
16 Besides the effects of the altered mainstem physical environment on the reproduction,
17 growth, survival, and distribution of native fishes in the Colorado River below Glen Canyon
18 Dam, past introductions of nonnative fish species, both intentional and accidental, have affected
19 native fish in the Colorado River and its tributaries downstream of Glen Canyon Dam. Coldwater
20 and/or warmwater nonnative fish exist in all fish-bearing waters in GCNP and GCNRA below
21 Glen Canyon Dam (see Section 3.4.4). These species can dominate the fish community in some
22 areas and may threaten native species survival. Nevertheless, habitats in the Colorado River and
23 its tributaries in GCNP support the largest remaining endangered humpback chub population,
24 and this population has been growing since the late 1990s (Coggins and Walters 2009) and is
25 now estimated at approximately 11,000 adults (Yackulic et al. 2014). Over this same time period,
26 the Grand Canyon fish community has also shifted from one dominated by nonnative salmonids
27 to one dominated by native species (Lauretta and Serrato 2006; Johnstone and Lauretta 2007;
28 Ackerman 2008; Makinster et al. 2010). It is hypothesized that the recent shift from nonnative to
29 native fish is due in part to warmer than average water temperatures and the decline of coldwater
30 salmonids (Ackerman 2008; Andersen 2009; Reclamation 2011c; Yackulic et al. 2014).

31
32 There are 11 species of native fishes that occur, may occur, or historically have occurred
33 within the study area (Table 3.5-1). Among these native species, five species—the humpback
34 chub, razorback sucker (*Xyrauchen texanus*), bluehead sucker (*Catostomus discobolus*),
35 flannelmouth sucker, and speckled dace—occur within the mainstem and its tributaries. Three
36 other species—the Zuni bluehead sucker (*Catostomus discobolus yarrowi*), Little Colorado
37 sucker (*Catostomus latipinnis* sp. 3), and Little Colorado spinedace (*Lepidomeda vittata*)—are
38 endemic to the upper reaches of the Little Colorado River. The remaining three species—the
39 bonytail chub (*G. elegans*), roundtail chub (*G. robusta*), and Colorado pikeminnow
40 (*Ptychocheilus lucius*)—have been extirpated from the mainstem between Glen Canyon Dam
41 and Hoover Dam. The extirpated species and those found only in the upper reaches of the Little
42 Colorado River are considered outside the affected area considered in this EIS. Currently,
43 five species of native fish are known to exist in the Colorado River between Glen Canyon Dam
44 and Lake Mead; these are discussed in detail in the following sections.

45



1
 2 **FIGURE 3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and**
 3 **Nonnative Fishes of the Colorado River System below Glen Canyon Dam (Source: Valdez and**
 4 **Speas 2007)**

5
 6
 7 **3.5.2.1 Special Status Fish Species**

8
 9 Two species of native fish that are listed under the Endangered Species Act of 1973
 10 (16 USC 1531, as amended)—the humpback chub and the razorback sucker—occur in the
 11 potentially affected portions of the Colorado River and its tributaries between Glen Canyon Dam
 12 and the inflow to Lake Mead. These two species are also designated as Arizona Species of
 13 Greatest Conservation Need (AZ-SGCN). In addition, two other native fish, the flannelmouth
 14 sucker and bluehead sucker, are included in the Arizona statewide conservation agreement for
 15 six native fish species (AZGFD 2006).
 16

1 **TABLE 3.5-1 Native Fish of the Colorado River through Glen and Grand Canyons**

Species	Listing Status ^a	Presence in Project Area ^b
Humpback chub (<i>Gila cypha</i>)	ESA-E, CH; AZ-SGCN	Lake Powell, Paria River confluence to Separation Canyon, Little Colorado River, Havasu Creek
Bonytail chub (<i>Gila elegans</i>)	ESA-E, CH; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon
Razorback sucker (<i>Xyrauchen texanus</i>)	ESA-E, CH; AZ-SGCN	Lake Powell; Lake Mead upstream to Lava Falls
Colorado pikeminnow (<i>Ptychocheilus lucius</i>)	ESA-E; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon.
Bluehead sucker (<i>Catostomus discobolus</i>)	AZ-SGCN	Paria River to Lake Mead, including tributaries
Flannelmouth sucker (<i>Catostomus latipinnis</i>)	NL	Lake Powell to Lake Mead
Speckled dace (<i>Rhinichthys osculus</i>)	NL	Glen Canyon Dam to Lake Mead, including tributaries

^a ESA = Endangered Species Act; E = listed as endangered; CH = federally designated critical habitat in project area; AZ-SGCN = Arizona Species of Greatest Conservation Need; NL = not listed.

^b Habitat and life history information is presented in species-specific discussions in this section.

Sources: 56 FR 54957; AZGFD (2001a,b; 2002a,b; 2003a); Andersen (2009); Bezzerides and Bestgen (2002); Coggins and Walters (2009); Makinster et al. (2010); Ptacek et al. (2005); Rees et al. (2005); Rinne and Magana (2002); FWS (2002a); Ward and Persons (2006); Woodbury et al. (1959); Gloss and Coggins (2005); GCMRC (2014); Albrecht et al. (2014).

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Humpback Chub

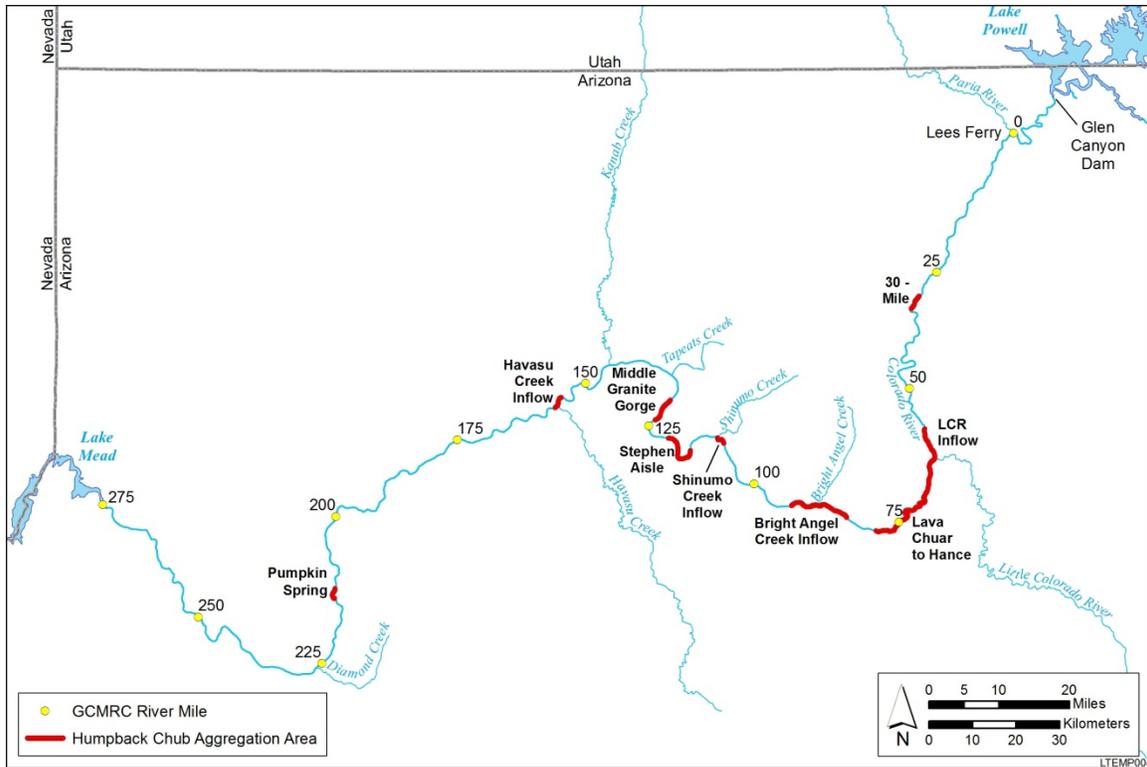
The humpback chub is a large, long-lived species endemic to the Colorado River system. This member of the minnow family may attain a length of 20 in., weigh 2 lb or more, and live as long as 40 years (Andersen 2009).

Distribution and Abundance. The humpback chub was federally listed as endangered in 1967. Historically, this species occurred throughout much of the Colorado River and its larger tributaries from below Hoover Dam upstream into Arizona, Utah, Colorado, and Wyoming (AZGFD 2001a). Currently, the humpback chub is restricted to six population centers, five in the upper Colorado River basin and one in the lower basin (FWS 2011a). The upper basin populations occur in: (1) the Colorado River in Cataract Canyon, Utah; (2) the Colorado River in Black Rocks, Colorado; (3) the Colorado River in Westwater Canyon, Utah; (4) the Green River

1 in Desolation and Gray Canyons, Utah; and (5) the Yampa River in Yampa Canyon, Colorado.
2 The only population in the lower basin occurs in the Colorado River in Marble Canyon, the
3 Grand Canyon, and Little Colorado River (FWS 2011a).
4

5 The Colorado River/Little Colorado River population is the largest of the six population
6 centers of the humpback chub. Within the Grand Canyon, this species is most abundant in the
7 vicinity of the confluence of the Colorado River and Little Colorado River (Paukert et al. 2006).
8 In addition, eight other areas (aggregation areas) where humpback chub are, or have been,
9 regularly collected have been identified; these aggregation areas are located at 30-Mile, Lava
10 Chuar-Hance, Bright Angel Creek inflow, Shinumo Creek inflow, Stephen Aisle, Middle Granite
11 Gorge, Havasu Creek inflow, and Pumpkin Spring (Figure 3.5-2; Valdez and Ryel 1995). In
12 addition, since 2009, translocations of humpback chub have been made by the U.S. Fish and
13 Wildlife Service (FWS) to introduce juvenile fish upstream of Chute Falls in the Little Colorado
14 River, and by NPS to introduce juvenile fish into Shinumo and Havasu Creeks, with the goal of
15 establishing additional spawning populations within the Grand Canyon (NPS 2012b, 2013g).
16 Survey data collected in 2013, 2014, and 2015 suggest that translocated humpback chub have
17 successfully spawned in Havasu Creek (NPS 2013g). Sampling conducted between October 2013
18 and September 2014 in western Grand Canyon between Lava Falls (RM 180) and Pearce Ferry
19 (RM 280) collected 144 juvenile humpback chub during sampling of the small-bodied fish
20 community, and 209 larval and juvenile humpback chub during sampling of the larval fish
21 community (Albrecht et al. 2014). These results suggest that young humpback chub are using
22 nursery and rearing habitats between RM 180 and RM 280 in the western Grand Canyon that are
23 not clearly associated with any of the aggregation areas identified above.
24

25 Monitoring data show that from 1989 through 2001, there was a steady decline of adult
26 humpback chub within the Little Colorado River aggregation in the Grand Canyon; estimated
27 numbers declined from approximately 11,000 adults (age 4+) in 1989 to about 5,000 adults in
28 2001 (Coggins et al. 2006; Coggins and Walters 2009) (Figure 3.5-3). However, since about
29 2001, the downward population trend reversed, with the estimated number of adult fish
30 increasing to approximately 8,000 fish by 2008 (Figure 3.5-3) (Coggins and Walters 2009).
31 Specific causes of the change in the humpback chub population trend are unclear, although
32 modified operations established by the 1996 ROD had gone into effect several years prior to the
33 increases observed after 2000. More recently, abundance estimates for 2009 to 2012 suggest the
34 population has continued to increase to approximately 11,000 adults (Figure 3.5-4)
35 (Yackulic et al. 2014). Factors suggested as being responsible for this estimated increase are
36 discussed later in this section. In addition, recent preliminary population estimates for humpback
37 chub aggregations suggest that humpback chub in several aggregations may have increased as a
38 result of (1) translocations to Shinumo and Havasu Creeks; (2) good production in the Little
39 Colorado River; (3) water temperatures that were about 1°C warmer since the early 2000s
40 (including significantly warmer than normal water temperatures in 2004, 2005, and 2011); and
41 (4) declines in trout abundance at the Little Colorado River inflow due to implementation of
42 trout control measures, a system-wide decline in trout abundance, or both (NPS and GCNP 2013;
43 Yackulic et al. 2014).
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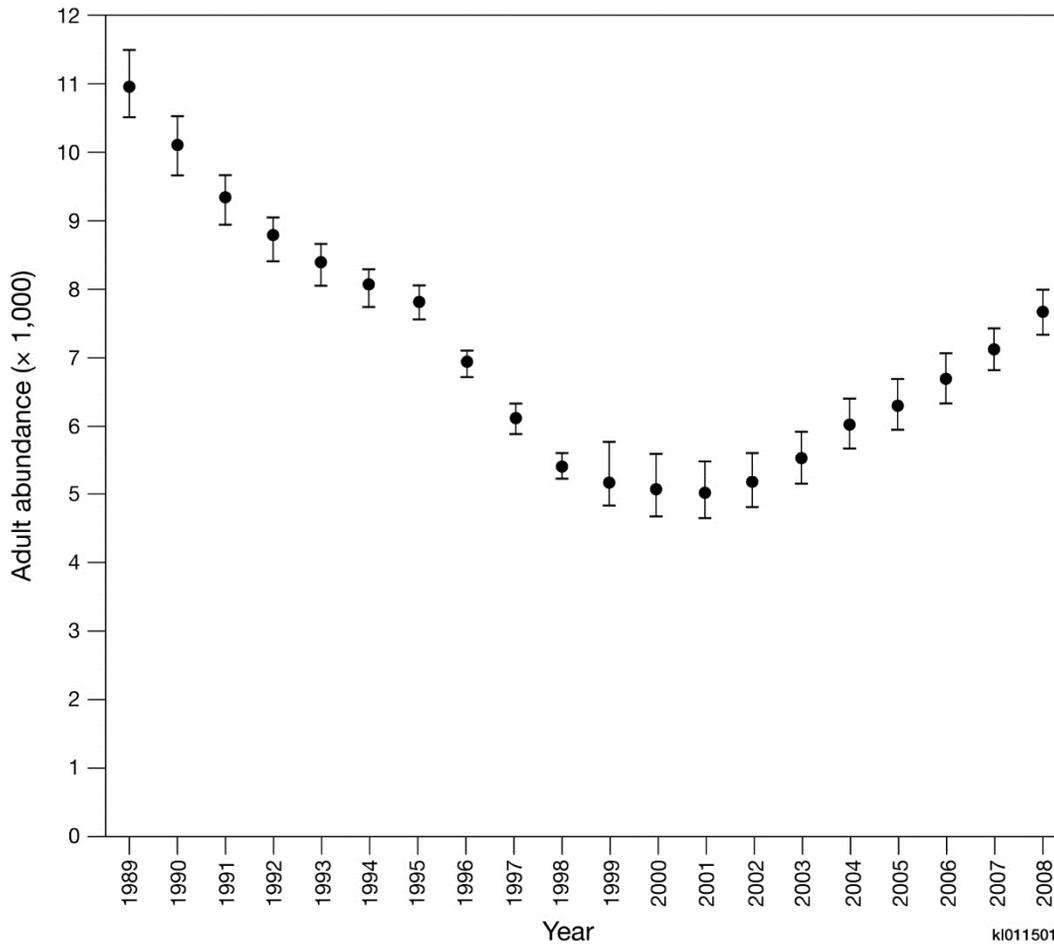
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FIGURE 3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead (Sources: VanderKooi 2011; NPS 2013b)

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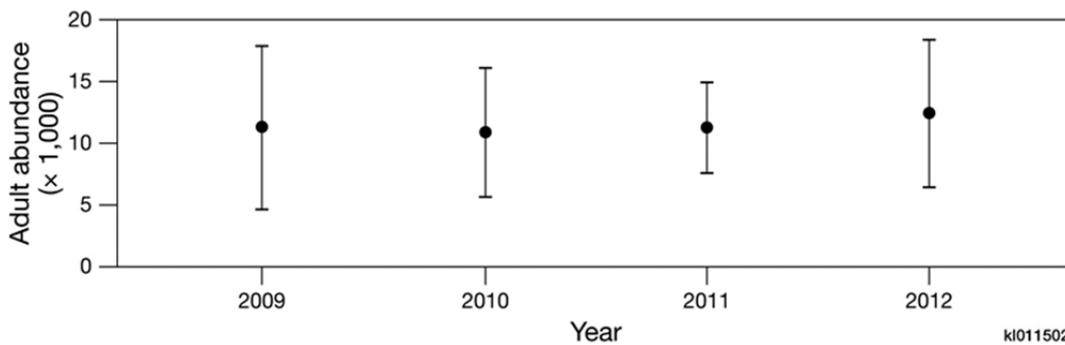
Habitat. Throughout the humpback chub’s current range, adults are found in turbulent, high-gradient canyon-bound reaches of large rivers (AZGFD 2001a) as well as in deep pools separated by turbulent rapids. Within the Grand Canyon, the humpback chub occurs primarily in the vicinity of the Little Colorado River (RM 30-110; Figure 3.5-2), with adults being associated with large eddy complexes. Converse et al. (1998) found that densities of subadult humpback chub in the mainstem Colorado River downstream of the Little Colorado River were greater along shoreline areas with vegetation, talus, and debris fans than in areas with bedrock, cobble, and sand substrates. One recent mark-recapture study reported that approximately 87% of recaptured fish were collected in the same mainstem river reach or tributary where they were originally tagged, with 99% of all recaptures occurring in and around the Little Colorado River (Paukert et al. 2006). However, some of the marked fish were determined to have moved as much as 96 mi throughout the Grand Canyon. In the Little Colorado River, adults inhabit a variety of habitats, including pools and areas below travertine dams (AZGFD 2001a). More recently, a study conducted in 2010 examined the movement of 30 radio-tagged adult humpback chub in the Colorado River during two months of fluctuating flow followed by two months of steady flow (Gerig et al. 2014). The radio-tagged fish were found to use eddies extensively while avoiding runs. During both flow treatments, the tagged fish exhibited only small daily movements of about 33 ft/day, and no effect of flow was observed on either habitat selection or movement.

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FIGURE 3.5-3 Estimated Adult Humpback Chub Abundance (Age 4+) from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age (Error bars represent minimum 95% confidence intervals and do not consider uncertainty in growth or mortality.) (Source: Coggins and Walters 2009)



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FIGURE 3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September, 2009 through 2012 (Error bars represent the 95% confidence intervals.) (Source: Yackulic et al. 2014)

1 The main spawning area for the humpback chub within the Grand Canyon is the Little
2 Colorado River, which provides warm temperatures suitable for spawning and shallow low-
3 velocity pools for larvae (Gorman 1994). Many of the larval fish remain in the Little Colorado
4 River for one or more years, and growth rates and survival are relatively high compared to
5 estimates for the colder waters of the mainstem Colorado River (Dzul et al. 2014). Spring
6 abundance estimates for age-1 humpback chub within the Little Colorado River from 2009 to
7 2012 ranged from approximately 1,000 to more than 9,000 individuals (Dzul et al. 2014). Within
8 the Little Colorado River, young humpback chub prefer shallow, low-velocity near-shore pools
9 and backwaters; they move to deeper and faster areas with increasing size and age
10 (AZGFD 2001a). In the mainstem of the Colorado River, young-of-the-year fish may be found in
11 backwater and other near-shore, slow-velocity areas that serve as nursery habitats (Valdez and
12 Ryel 1995; Robinson et al. 1998; AZGFD 2001a; Stone and Gorman 2006). Juvenile humpback
13 chub (<3 years old) have been collected in all types of near-shore habitats by the Humpback
14 Chub Near-shore Ecology Study, with the highest numbers collected from talus slopes (Dodrill
15 et al. 2015).

16
17 These near-shore habitats may be beneficial to the humpback chub (and other native
18 fishes) as they provide shallow, productive, warm refugia for juvenile and adult fish
19 (Reclamation 1995; Hoffnagle 1996). Temperature differences between main channel and near-
20 shore habitats can be pronounced in backwaters and other low-velocity areas. The extent of
21 warming is variable and depends on the timing of the daily minimum and maximum flows, the
22 difference between air and water temperatures, and the topography and orientation of the
23 backwater relative to solar insolation (Korman et al. 2006). For example, summertime water
24 temperatures in backwaters have been reported to be as high as 25°C (77°F) while main channel
25 temperatures are near 10°C (50°F) (Maddux et al. 1987). The amount of warming that occurs in
26 backwaters is affected by daily fluctuations, which drain and fill backwater habitats with cold
27 main channel waters (Valdez 1991; Angradi et al. 1992; AZGFD 1996; Behn et al. 2010). During
28 the low steady summer flow experiment conducted in 2000, temperatures in one backwater were
29 as much as 13°C (23°F) warmer than in the adjacent main channel during some portions of the
30 day; temperature differences were much less at night (Vernieu and Anderson 2013). Backwater
31 temperatures in summer have been reported to be as much as 2 to 4°C (3.6 to 7.2°F) warmer
32 under steady flows than under fluctuating flows (Hoffnagle 1996; Trammell et al. 2002;
33 Korman et al. 2006; Anderson and Wright 2007). In general, the levels of warming observed in
34 nearshore areas and backwaters during the low summer steady flows in 2000 persisted only for
35 short periods of time and were smaller than seasonal changes in water temperatures.
36 Consequently, temperature effects on native fishes were probably small.

37
38 Although the use of thermal refugia such as backwaters has been documented in a variety
39 of systems (e.g., Tyus and Haines 1991; Bodensteiner and Lewis 1992; Torgersen et al. 1999;
40 Ebersole et al. 2001; Westhoff et al. 2014), the overall importance of backwater habitats in the
41 Colorado River relative to humpback chub survival and recruitment is uncertain
42 (Reclamation 2011c). While juvenile humpback chub have been reported to show positive
43 selection for backwater habitats, the spatial extent of such habitats in the Colorado River is small
44 compared to other nearshore habitats such as talus slopes (Dodrill et al. 2015). Dodrill et al.
45 (2015) reported that the total abundance of juvenile humpback chub was much higher in talus
46 than in backwater habitats, and that when relative densities were extrapolated using estimates of

1 backwater prevalence after a controlled flood, the majority of juvenile humpback chub were still
2 found outside of backwaters. This suggests that the role of controlled floods in influencing native
3 fish population trends in the Colorado River may be limited.
4
5

6 **Life History.** The humpback chub is primarily an insectivore, with larvae, juveniles, and
7 adults all feeding on a variety of aquatic insect larvae and adults, including dipterans (primarily
8 chironomids and simuliids), Thysanoptera (thrips), Hymenoptera (ants, wasps, bees), and
9 amphipods (such as *Gammarus lacustris*) (Kaeding and Zimmerman 1983; AZGFD 2001a).
10 Feeding by all life stages may occur throughout the water column as well as at the water surface
11 and on the river bottom.
12

13 The Grand Canyon humpback chub population reproduces primarily in the lower 8 mi of
14 the Little Colorado River (AZGFD 2001a). Adults move into the Little Colorado River from the
15 Colorado River to spawn from March to May (Kaeding and Zimmerman 1983; Gorman and
16 Stone 1999; FWS 2008). Relatively little spawning and juvenile rearing occur in the mainstem of
17 the Colorado River, primarily because of the cold mainstem water temperatures
18 (Andersen 2009). This species requires a minimum temperature of 16°C (61°F) to reproduce, but
19 mainstem water temperatures typically have range from 7 to 12°C (45 to 54°F) because of water
20 releases from Glen Canyon Dam (Andersen 2009). Drought-induced warming has resulted in
21 mainstem water temperatures since 2003 consistently exceeding 12°C (54°F) in the summer and
22 fall months. Although some increases in spawning may have played a role in the estimated
23 increase in the humpback chub population in the system since that time, it is likely that the
24 increased temperatures resulted in higher survival of juveniles in the mainstem (Andersen 2009;
25 Coggins and Walters 2009; Yackulic et al. 2014).
26

27 Following spawning, larvae have been reported to drift in the Little Colorado River from
28 April through June, and many drift out into near-shore habitats of the Colorado River
29 (FWS 2008). Robinson et al. (1998) estimated about 38,000 larval humpback chub drifted from
30 the Little Colorado River into the mainstem in May and June 1993. Juveniles generally have
31 lower monthly rates of movement than adults, with the exception of a high probability of
32 juveniles being transported from the Little Colorado River to the Colorado River during high
33 flows of the monsoon season, when numbers of juvenile humpback chub in the mainstem have
34 been documented to increase by as much as 4,000 fish (Yackulic et al. 2014).
35

36 Although survival of larval and juvenile fish in the mainstem was once thought to be very
37 rare because of seasonally constant, low water temperatures (Clarkson and Childs 2000), more
38 recent information suggests that juveniles can successfully rear to adulthood in the Colorado
39 River mainstem, at least under recent environmental conditions that include warmer water
40 (Yackulic et al. 2014). Increasing water temperatures have been shown in the laboratory to
41 increase hatching success, larval survival, larval and juvenile growth, and improve swimming
42 ability and reduce predation vulnerability (Hamman 1982; Ward 2011; Ward and Morton-Starnes
43 2015). Yackulic et al. (2014) postulated that, with warmer water, growth and survival of
44 juveniles in the mainstem will be greater and result in increased mainstem recruitment, and thus
45 contribute to the overall adult population. Increased water temperatures may also affect predation
46 of young-of-the-year humpback chub by rainbow and brown trout (*Salmo trutta*) (Ward 2011;

1 Ward and Morton-Starner 2015; Yard et al. 2011). Ward and Morton-Starner (2015) conducted
2 laboratory studies that indicated predation success of rainbow trout on young-of-the-year
3 humpback chub decreased from approximately 95 to 79% as water temperature increased from
4 10°C to 20°C (50°F to 68°F); predation success by brown trout was about 98% and did not
5 change significantly over the same temperature range. Yard et al. (2011) examined the effects of
6 temperature on trout piscivory in the Colorado River and reported no relationship between water
7 temperature and the incidence of piscivory by rainbow trout, but a significant positive correlation
8 was found between water temperature and the incidence of piscivory for the brown trout.
9

10
11 **Factors Affecting Distribution and Abundance in the Grand Canyon.** These factors
12 include habitat alterations associated with dams and reservoirs and the introduction of nonnative
13 fishes, which act as competitors and/or predators of the humpback chub (see Section 3.5.3.3)
14 (AZGFD 2001a; Andersen 2009; Yard et al. 2011; Kennedy et al. 2013). The abundance and
15 distribution of nonnative fishes are discussed in Section 3.5.3. In addition, the Colorado River
16 now includes nonnative fish parasites, such as the Asian tapeworm and anchor worm, which may
17 infect some humpback chub and affect survival (Clarkson et al. 1997; Andersen 2009). While
18 coldwater releases from Glen Canyon Dam have been implicated in affecting reproduction and
19 recruitment of humpback chub (and other native fishes) in the mainstem Colorado River, warmer
20 water temperatures in the mainstem over the last decade may be providing some temporary
21 benefit and contributing to the improving status of the humpback chub (Reclamation 2011a).
22

23 Population estimates indicate that the number of adult humpback chub in the Grand
24 Canyon has been increasing since 2000 (Figures 3.5-3 and 3.5-4), and a number of factors have
25 been suggested as being responsible for the observed increases, including experimental water
26 releases, trout removal, declines in trout abundance due to low dissolved oxygen levels during
27 2006, and drought-induced warming (Andersen 2009; Coggins and Walters 2009). Even though
28 HFE water releases from Glen Canyon Dam between 2000 and 2008 may have improved some
29 habitat characteristics (e.g., backwaters and flow regimes) for humpback chub and other native
30 fish, the limited availability of suitably warm water temperatures in the mainstem may have
31 constrained the potential for positive population responses (Kennedy and Ralston 2011). Some
32 experimental releases, such as the November HFE in 2004, may have adversely affected rainbow
33 trout and improved humpback chub habitat along the main channel (Korman et al. 2010).
34 However, the March 2008 HFE may have improved the quality of spawning habitat for rainbow
35 trout in the Lees Ferry reach, and the abundance of rainbow trout (using catch-per-unit-effort as a
36 surrogate for abundance) in this reach was reported to be about 300% larger in 2009 than in 2007
37 (about 3.9 fish per minute vs. 1.3 fish per minute, respectively) (Makinster et al. 2011), and a
38 similar increase in rainbow trout abundance between 2007 and 2009 was observed at the Little
39 Colorado River confluence (RM 56–69) (Kennedy and Ralston 2011). The effects of HFEs on
40 trout abundance are discussed in more detail in Section 3.5.3.4.
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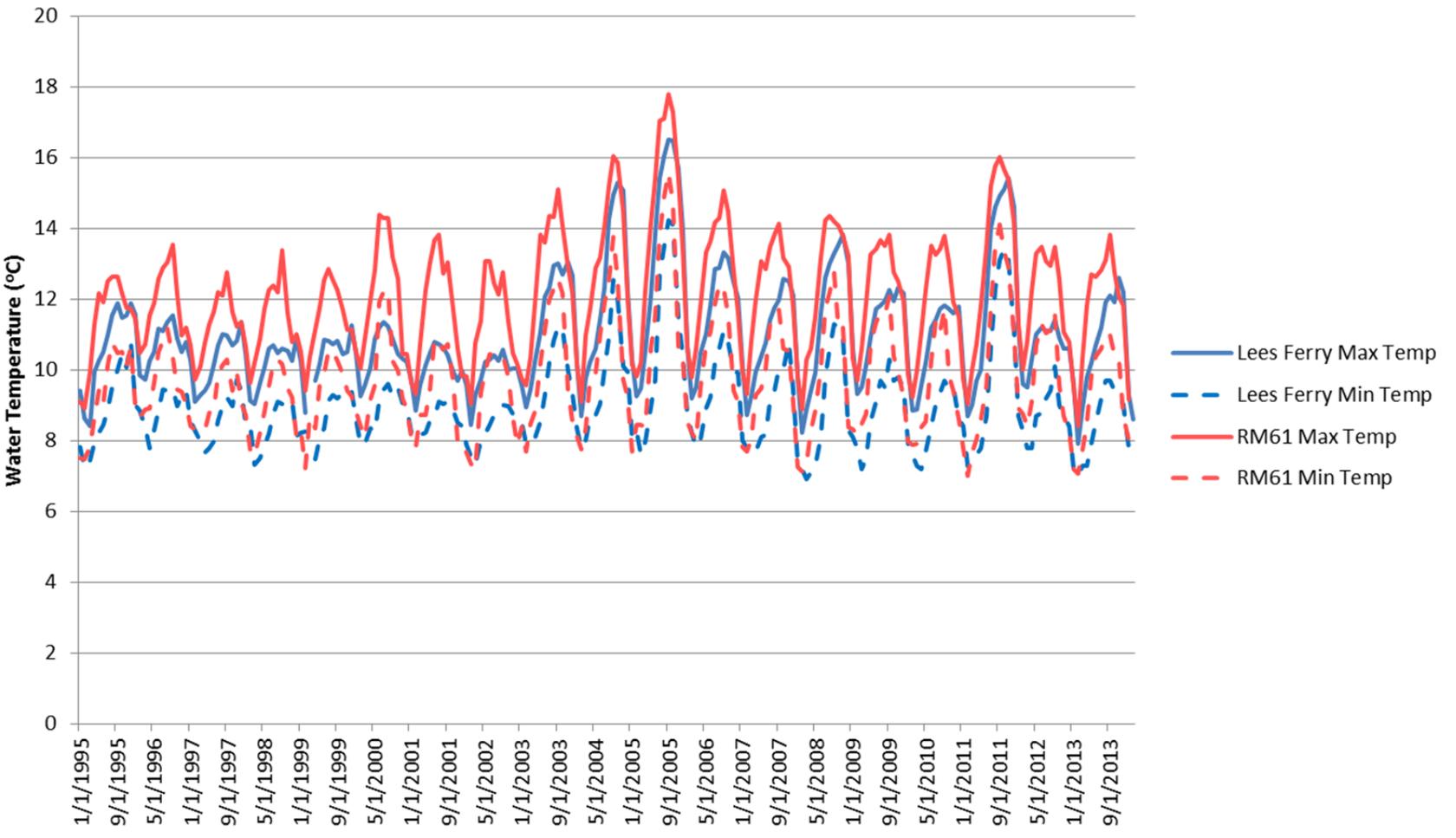
42 Predation by rainbow and brown trout at the Little Colorado River confluence has been
43 identified as an additional mortality source affecting humpback chub survival, reproduction, and
44 recruitment (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2011). Predation by
45 channel catfish and black bullhead (*Ictalurus melas*) are also thought to threaten humpback chub
46 in the Grand Canyon, particularly if warmer water conditions occur (NPS and GCNP 2013).

1 Because of their size, adult humpback chub are less likely to be preyed on by trout; however,
2 emergent fry, young-of-the-year, and juvenile humpback chub are susceptible to predation in the
3 mainstem Colorado River in the vicinity of the Little Colorado River (Yard et al. 2011).
4

5 Experimental removal of nonnative brown and rainbow trout was conducted in the
6 Colorado River in Grand Canyon between 2003 and 2006 (see Section 3.5.3.4). Twenty-three
7 trips to remove trout from the vicinity of the confluence of the Little Colorado River (RM 56–66)
8 resulted in the removal of more than 23,000 nonnative fish (mostly rainbow trout). During this
9 time, the rainbow trout population in the Colorado River in the vicinity of the Little Colorado
10 River was decreased by more than 80% (Andersen 2009). Although the estimated humpback
11 chub abundance increased during this time (Figure 3.5-3), the relationship between trout removal
12 at the Little Colorado River, decreases in trout abundance, and increases in humpback chub
13 abundance are not clear; trout abundance declined throughout the mainstem Colorado River
14 downstream of Glen Canyon Dam during the same general timeframe (Coggins et al. 2011).
15 Increased numbers of humpback chub may also be attributable to a variety of other factors,
16 including warmer water temperatures that occurred during this time, the HFE experimental
17 flows, or a general decrease in rainbow trout abundance throughout the Grand Canyon ecosystem
18 (Andersen 2009; Coggins et al. 2011; also see Section 3.5.3.4).
19

20 To aid in the mechanical trout removal effort, an experimental nonnative fish suppression
21 flow regime from Glen Canyon Dam was implemented between January and March in 2003 and
22 2004 (Reclamation 2011c). These flows were intended to reduce rainbow trout abundance in the
23 Lees Ferry reach by increasing mortality of incubating life stages. While the experimental flows
24 were successful in reducing hatching and survival of young trout, density-dependent factors
25 compensated with higher survival and growth of the remaining fish (Korman et al. 2005), and
26 thus the flows were not effective in limiting trout recruitment. However, those flows differ from
27 the trout management flows being proposed under many alternatives in this DEIS. See
28 Section 3.5.3.4 for more detailed discussions on both the nonnative fish suppression flows and
29 mechanical trout removal.
30

31 As previously discussed, the cold water temperatures in the main channel are below the
32 temperature needed for spawning, egg incubation, and growth of the humpback chub (as well as
33 for most native fish) (Figure 3.5-1). Survival of humpback chub young in the mainstem is
34 thought to be low because of cold mainstem water temperatures (Clarkson and Childs 2000;
35 Robinson and Childs 2001), which may limit hatching success, reduce larval survival and larval
36 and juvenile growth (Coggins and Pine 2010), reduce swimming ability, and increase predation
37 vulnerability (Ward and Bonar 2003; Ward 2011). Water temperatures in the mainstem Colorado
38 River have generally been elevated over the last decade (Figure 3.5-5). These temperatures are
39 not optimal for humpback chub spawning and growth. However, juveniles can now successfully
40 rear to adulthood in the Colorado River mainstem, and mainstem recruitment is likely
41 contributing to the overall adult population that now appears to be stable or increasing
42 (Yackulic et al. 2014; Figure 3.5-4).
43
44



1
2 **FIGURE 3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence (RM 61), 1995 to Present**
3 **(Source: USGS 2014b)**
4

1 Water temperatures below Glen Canyon Dam began increasing in 2003 as a result of
2 drought conditions that lowered the level of Lake Powell and resulted in the release of warmer
3 water from the dam (Andersen 2009; Andersen et al. 2010); temperatures have remained
4 elevated relative to operations during the 1980s and 1990s due to continued drought-induced
5 lower Lake Powell reservoir levels and somewhat due to relatively high inflow in 2008, 2009,
6 and 2011. In 2005, maximum mainstem water temperature exceeded 15°C (59°F) at Lees Ferry
7 and approached 18°C (64°F) in the vicinity of the Little Colorado River (RM 61), the warmest
8 temperature at those locations since the reservoir was filled in 1980 (Figure 3.5-5). Maximum
9 water temperature in the mainstem at Lees Ferry reached about 14°C (57°F) in 2008
10 (USGS 2014b), similar to temperatures in 2003 when drought effects from low Lake Powell
11 levels began to raise Glen Canyon Dam release temperatures. In 2011, maximum mainstem
12 water temperatures at Lees Ferry and the Little Colorado River confluence (RM 61) reached
13 about 15°C (59°F) and 16°C (61°F), respectively (Figure 3.5-5). This warmer water appears to
14 have benefitted the humpback chub and other native fish, but they may also have benefitted
15 nonnative warmwater species (e.g., channel catfish, striped bass) that are more abundant farther
16 downstream in the Grand Canyon (Andersen 2009; Coggins and Walters 2009; Kennedy and
17 Ralston 2011).

18 19 20 **Razorback Sucker**

21
22 The razorback sucker is a large river sucker (Catostomidae) endemic to the Colorado
23 River system. It is a large fish, with adults reaching lengths up to 3 ft and weighing as much as
24 13 lb (FWS 2002a), and may live 40 years or more (AZGFD 2002a).

25
26
27 **Distribution and Abundance.** The razorback sucker was listed as endangered in 1991
28 (56 FR 54957). The species is endemic to large rivers of the Colorado River Basin from
29 Wyoming to Mexico. Currently, it occurs in the Green River, upper Colorado River, and
30 San Juan River subbasins; the lower Colorado River between Lake Havasu and Davis Dam; Lake
31 Mead and Lake Mohave; and tributaries of the Gila River subbasin (FWS 2002a), and Lake
32 Powell (Francis et al. 2015). The largest remaining wild-spawned population was in Lake
33 Mohave (Marsh et al. 2003); however, the wild fish have died from old age and the population is
34 being supported by rearing of wild-spawned larvae in hatcheries and release of those fish to the
35 lake. Within the Grand Canyon, this species historically occurred in the Colorado River from
36 Lake Mead into Maxson Canyon (RM 252.5), with several documented captures at the Little
37 Colorado River inflow in 1989 and 1990, and from the Paria River mouth (in 1963 and 1978, as
38 reported in NPS and GCNP 2013). The population in Lake Mead is believed to be self-
39 sustaining, and in 2002 was estimated to consist of about 400 adults (FWS 2002a). More recently
40 (2009–2011), the lakewide population in Lake Mead was estimated to range from 733 to 982 fish
41 (Shattuck et al. 2011).

42
43 Until recently, the last razorback sucker collected from the Grand Canyon (RM 39.3) was
44 caught in 1993, and the species was considered extirpated from the Grand Canyon. However,
45 razorback suckers and flannelmouth-razorback sucker hybrids have recently been captured from
46 the western Grand Canyon (Bunch, Makinster et al. 2012; Bunch, Osterhoudt et al. 2012;

1 Rogowski and Wolters 2014; Rogowski, Wolters et al. 2015). Four fish that were sonic-tagged in
2 Lake Mead in 2010 and 2011 were detected in the spring and summer of 2012 in GCNP up to
3 Quartermaster Canyon (RM 260) (Kegerries and Albrecht 2012, as cited in NPS and
4 GCNP 2013). An additional untagged adult razorback sucker was captured in GCNP near
5 Spencer Creek (RM 246) in October 2012 (Bunch, Osterhoudt et al. 2012), and another adult was
6 collected in late 2013 (GCMRC 2014). Recent sampling of channel margin habitats has also
7 documented 462 razorback sucker larvae as far upstream as RM 179 (just upstream of Lava
8 Falls), indicating that spawning is occurring in the mainstem river in western Grand Canyon
9 (Albrecht et al. 2014). Adult razorback suckers have also recently been located as far upstream
10 as RM 184.4 near Lava Falls, and numerous adults have been documented in western Grand
11 Canyon, indicating that the species utilizes the Colorado River above the Lake Mead inflow area
12 more than previously thought (Albrecht et al. 2014).

13
14

15 **Habitat.** The razorback sucker uses a variety of habitats, ranging from mainstream
16 channels to slow backwaters of medium and large streams and rivers (AZGFD 2002a). In rivers,
17 habitat requirements of adults in spring include deep runs, eddies, backwaters, and flooded off-
18 channel areas; in summer, runs and pools, often in shallow water associated with submerged
19 sand bars; and in winter, low-velocity runs, pools, and eddies (FWS 2002a). In reservoirs, adults
20 prefer areas with water depths of 3 ft or more over sand, mud, or gravel substrates. Young
21 require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and
22 inundated floodplains along rivers, and coves or shorelines in reservoirs (FWS 2002a). Recent
23 captures of larval razorback sucker in western Grand Canyon found the highest density of larvae
24 in isolated pools, which comprised less than 2% of all habitat sampled (Albrecht et al. 2014).
25 Critical habitat was designated for this species in 1994, and includes the Colorado River and its
26 100-year floodplain from the confluence of the Paria River downstream to Hoover Dam
27 (a distance of about 500 mi), including Lake Mead to full pool elevation (59 FR 13374).

28
29

30 **Life History.** Both adults and immature fish are omnivorous, feeding on algae,
31 zooplankton, and aquatic insect larvae. In Lake Mohave, their diet has been reported to be
32 dominated by zooplankton, diatoms, filamentous algae, and detritus (Marsh 1987).

33

34 Razorback suckers exhibit relatively fast growth the first 5 to 7 years of life, after which
35 growth slows and possibly stops (AZGFD 2002a). Both sexes are sexually mature by age 4.
36 Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at
37 widely ranging flows and at water temperatures typically greater than 14°C (57°F) (FWS 2002a).
38 In reservoirs, spawning occurs over rocky shoals and shorelines. Temperatures for spawning, egg
39 incubation, and growth of this species range from 14 to 25°C (57 to 77°F) (Figure 3.5-1).
40 Hatching success is temperature dependent, with complete mortality occurring at temperatures
41 less than 10°C (50°F); optimum temperatures for adults are around 22–25°C (72–77°F)
42 (AZGFD 2002a).

43

44 Historically, this species exhibited upstream migrations in spring for spawning, although
45 current populations include groups that are sedentary and others that move extensively
46 (Minckley et al. 1991). Adults in the Green River subbasin have been reported to move as much

1 as 62 mi to specific areas to spawn (Tyus and Karp 1990). In Lake Mohave, individuals have
2 been reported to move 12 to 19 mi between spring spawning and summer use areas
3 (Mueller et al. 2000).
4
5

6 **Factors Affecting Distribution and Abundance in the Grand Canyon.** The decline of
7 the razorback sucker throughout its range has been attributed primarily to habitat loss due to dam
8 construction, loss of spawning and nursery habitats as a result of diking and dam operations, and
9 alteration of flow hydrology (AZGFD 2002a). For example, the 80% reduction in the historical
10 distribution of this species has been attributed to the construction of Hoover, Parker, Davis, and
11 Glen Canyon Dams on the Colorado River and Flaming Gorge Dam on the Green River
12 (Valdez et al. 2012). In addition, competition with and predation by nonnative fishes have also
13 been identified as important factors in the decline of this species (Minckley et al. 1991;
14 FWS 2002a). In the Grand Canyon, the decline of native fish, including razorback sucker, has
15 been attributed in large part to an increased diversity and abundance of nonnative fishes along
16 with the effects of Glen Canyon Dam on water temperatures, flow, and sediment (Gloss and
17 Coggins 2005).
18

19 As described above, recent efforts to better understand the use of western Grand Canyon
20 by razorback sucker has revealed that the species is more widespread there than previously
21 thought, occupies and spawns in the river from at least Lava Falls to throughout Lake Mead, and
22 maintains a reproducing population in the project area (Albrecht et al. 2014). Currently, there is
23 little information on the habitat use and life history needs for the species in Grand Canyon and
24 Lake Mead. Additional research and monitoring are needed to better understand the management
25 implications for recovery of razorback sucker in this reach of its range (Albrecht et al. 2014).
26
27

28 **Bluehead Sucker**

29

30 The bluehead sucker is a member of the Catostomidae family. Adults may reach 12 to
31 18 in. in total length in large rivers but may be smaller in smaller tributaries; they may live from
32 6 to 8 years to as many as 20 years (Sigler and Sigler 1987; Bezzerides and Bestgen 2002;
33 AZGFD 2003a). This species has been reported to be as large as 20 in. long in the mainstem
34 Colorado River in Grand Canyon, with tributary fish being smaller (AZGFD 2003a). A related
35 subspecies, the Zuni bluehead sucker, occurs in the headwaters of the Little Colorado River
36 along with bluehead suckers that are the same subspecies as those that occur in the mainstem
37 Colorado River (AZGFD 2002b).
38
39

40 **Distribution and Abundance.** Bluehead sucker populations are declining throughout the
41 species' historic range, and the species has been identified as an AZ-SGCN (AZGFD 2012). The
42 bluehead sucker is included in the Arizona statewide conservation agreement for six native fish
43 species (AZGFD 2006). In the Colorado River Basin, this species is found in the Colorado River
44 and its tributaries from Lake Mead upstream into Arizona, Colorado, New Mexico, Utah, and
45 Wyoming. This species is also found in the Snake River (Idaho and Wyoming), the Bear River

1 (Idaho and Utah), and Weber River (Utah and Wyoming) drainages (Bezzerrides and
2 Bestgen 2002; AZGFD 2003a).

3
4 Within the Grand Canyon, the bluehead sucker occurs in the Colorado River mainstem
5 and its tributaries, including the Little Colorado River, Clear Creek, Bright Angel Creek, Kanab
6 Creek, and Havasu Creek (Rinne and Magana 2002; AZGFD 2003a; Ptacek et al. 2005; NPS and
7 GCNP 2013), and prior to 2014, in Shinumo Creek (Healy et al. 2014). Annual fish monitoring
8 conducted between 2000 and 2009 in the Colorado River between Glen Canyon Dam and the
9 inflow to Lake Mead show the bluehead sucker to be present in all reaches of the river
10 (Makinster et al. 2010). This species is very rare in the upper sections of GCNP and increases in
11 number near the Little Colorado River inflow and downstream (Bunch, Makinster et al. 2012;
12 Bunch, Osterhoudt et al. 2012).

13
14 Abundance estimates using monitoring data and Age-Structured Mark-Recapture
15 (ASMR) models show the abundance of age-1 (juvenile) bluehead suckers in the Grand Canyon
16 declined from 1990 to 1995, increased from 1995 to 2003, and then declined through 2009
17 (Walters et al. 2012). Similar estimates for age-4 (adult) fish show abundance began increasing
18 from the late 1990s until 2005 or 2006, after which abundance also declined. The estimated
19 abundance of age-1 bluehead sucker has ranged from 1,000 or less to as many as 60,000 fish
20 between 2000 and 2009 (Walters et al. 2012). Estimated abundance of age-4+ adults during this
21 same period ranged from about 5,000 to as many as 75,000 fish. Although the bluehead sucker
22 was likely extirpated from Shinumo Creek following fires and flooding in 2014 (Healy et al.
23 2014), relatively high numbers of individuals remain in the lower Colorado River between
24 Lava Falls Rapid (RM 179) and Lake Mead (Bunch, Makinster et al. 2012; Bunch,
25 Osterhoudt et al. 2012). Recent sampling of the larval fish community in western Grand Canyon
26 between Lava Falls and Pearce Ferry collected bluehead sucker larvae throughout the study area
27 (Albrecht et al. 2014). In this study area, the bluehead sucker was the most abundant species in
28 the larval fish community, comprising almost 40% of the total catch.

29
30
31 **Habitat.** The bluehead sucker typically inhabits large streams, and may also occur in
32 smaller streams and creeks (Sigler and Sigler 1987; AZGFD 2003a). Riverine habitats may range
33 from cold (12°C [54°F]), clear streams to warm (28°C [82°F]), very turbid rivers. Large adults
34 live in deep water (6 to 10 ft), while juveniles use shallower, lower velocity habitats (Bezzerrides
35 and Bestgen 2002). In clear streams, the bluehead sucker stays in deep pools and eddies during
36 the day and moves to shallower habitats (e.g., riffles, tributary mouths) to feed at night, while in
37 turbid waters they may use shallow areas throughout the day (Beyers et al. 2001;
38 AZGFD 2003a). In Grand Canyon, larval and young bluehead suckers inhabit backwater areas
39 and other near-shore low-velocity habitats such as eddies, embayments, and isolated pools
40 (Childs et al. 1998; AZGFD 2003a; Albrecht et al. 2014).

41
42
43 **Life History.** The bluehead sucker is an omnivorous benthic forager. It feeds by scraping
44 algae, invertebrates, and other organic and inorganic materials off rocks and other hard surfaces
45 (Ptacek et al. 2005). Larvae drift to backwaters and other areas of low current where they feed on
46 diatoms, zooplankton, and dipteran larvae.

1 In the lower Colorado River, this species spawns in spring and summer after water
2 temperatures exceed 16°C (61°F). Spawning in Grand Canyon tributaries occurs mid-March
3 through June in water depths ranging from a few inches to more than 3 ft and at temperatures of
4 16 to 20°C (61 to 68°F) over gravel-sand and gravel-cobble substrates (AZGFD 2003a; NPS and
5 GCNP 2013). In Kanab Creek, spawning has been reported to occur at temperatures of
6 18.2–24.6°C (64.8–76.3°F) (Maddux and Kepner 1988). Smaller tributaries may provide nursery
7 grounds for populations of large adjacent rivers (Rinne and Magana 2002).
8
9

10 **Factors Affecting Distribution and Abundance in the Grand Canyon.** As with the
11 humpback chub, decreases in distribution and abundance of the bluehead sucker throughout its
12 range, as well as in portions of the Colorado River and its tributaries below Glen Canyon Dam,
13 have been attributed to two main factors: (1) habitat degradation through loss, modification,
14 and/or fragmentation and (2) interactions with nonnative species (Gloss and Coggins 2005;
15 Ptacek et al. 2005). Disturbance related to fire and flooding may also influence bluehead sucker
16 distribution in tributaries. The construction and operation of Glen Canyon Dam has altered
17 downstream temperature and flow regimes. Cold tailwaters below dams are below temperatures
18 needed for spawning and recruitment (Rinne and Magana 2002; Walters et al. 2012). Past
19 recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then
20 increased after 2000; the largest recruitment estimates coincided with brood years 2003 and
21 2004, when there was a sudden increase in mainstem water temperatures because of warmer
22 releases from Glen Canyon Dam (Walters et al. 2012).
23

24 The introduction of nonnative fish has increased competition with and predation on
25 bluehead sucker (AZGFD 2003a; Ptacek et al. 2005). Large nonnative predators such as channel
26 catfish and trout, mid-sized fish like sunfishes, and even smaller nonnative minnows may all
27 prey on one or more life stages of the bluehead sucker (Rinne and Magana 2002;
28 Ptacek et al. 2005; Yard et al. 2011).
29
30

31 **3.5.2.2 Other Native Species**

32

33 Two other native fish species occur in the affected area of the Colorado River and its
34 tributaries between Glen Canyon Dam and the inflow to Lake Mead—flannelmouth sucker and
35 speckled dace (Table 3.5-1). Both speckled dace and flannelmouth sucker are identified as
36 AZ-SGCN (AZGFD 2012). In addition, the flannelmouth sucker is included in the Arizona
37 statewide conservation agreement for six native fish species (AZGFD 2006). The flannelmouth
38 sucker and speckled dace are discussed below.
39
40

41 **Flannelmouth Sucker**

42

43 The flannelmouth sucker is member of the sucker family (Catostomidae). It is a relatively
44 large fish, with a maximum total length of greater than 2 ft and a maximum weight exceeding
45 3 lb (AZGFD 2001b; Rees et al. 2005). It is a long-lived species, living as long as 30 years
46 (AZGFD 2001b).

1 **Distribution and Abundance.** Historically, the flannelmouth sucker ranged throughout
2 the Colorado River Basin, in moderate to large rivers in Arizona, California, Colorado, Nevada,
3 New Mexico, Utah, and Wyoming (Bezzerrides and Bestgen 2002; Rees et al. 2005). Within the
4 Grand Canyon, this species may be found in the mainstem Colorado River and its tributaries
5 including the Little Colorado and Paria rivers and Shinumo, Bright Angel, Kanab, and Havasu
6 Creeks (Douglas and Marsh 1998; Weiss 1993; AZGFD 2001b; Bezzerrides and Bestgen 2002).
7 In contrast to bluehead sucker, flannelmouth sucker are only found below the barrier falls in
8 Shinumo and Havasu Creeks. Annual monitoring conducted between 2000 and 2009 found the
9 flannelmouth sucker to be present in all reaches of the river between Lees Ferry and the inflow to
10 Lake Mead (Makinster et al. 2010). Abundance, across all reaches and measured as catch-per-
11 unit-effort, has been increasing since 2000, especially since about 2004 (Makinster et al. 2010).
12 However, abundance has been decreasing within individual reaches between RM 0 and RM 179
13 since about 2005, but increasing downstream of RM 179. Recent surveys of the small-bodied and
14 larval fish communities in western Grand Canyon (Lava Falls to Pearce Ferry) found
15 flannelmouth sucker to be present throughout the reach, accounting for over 38% of the total
16 larval catch in this area (Albrecht et al. 2014).

17
18 Abundance estimates using monitoring data and ASMR models show an increase in the
19 abundance of age-1 (juvenile) and age-4 (adult) flannelmouth suckers in the Grand Canyon
20 between 2000 and 2008 (Walters et al. 2012). Abundance of age-1 flannelmouth sucker
21 increased from about 2,500 in 2000 to about 10,000 in 2008, while abundance of age 4+ adults
22 increased from about 10,000 to about 25,000 for this same period (Walters et al. 2012). Other
23 abundance estimates based on electrofishing catch-per-unit-effort for this same time period
24 showed an increase in abundance from less than 1,000 in 2000 to about 12,000 in 2009, while the
25 estimated abundance of age-4+ adults increased from about 2,500 in 2001 to about 31,000 in
26 2009 (Walters et al. 2012).

27
28
29 **Habitat.** This species prefers large to moderately large rivers. Adults may prefer deep
30 water when not feeding (Rinne and Minckley 1991), while larvae and young are often associated
31 with shallow, slow-moving near-shore areas such as backwaters and shoreline areas of slow runs
32 or pools (AZGFD 2001b; Rees et al. 2005). Although it is a riverine species, in the upper
33 Colorado River Basin the flannelmouth sucker has been collected from Flaming Gorge and
34 Fontenelle Reservoirs. In the Colorado River in Grand Canyon, subadults are found in eddies and
35 runs over sand bottoms. In the Little Colorado River, adult and juvenile flannelmouth suckers
36 use low-velocity, near-shore habitats with large amounts of cover during the daylight, and their
37 use of faster, more exposed mid-channel habitats increases at night (Gorman 1994). Juveniles
38 and adults may be considered habitat generalists, and can be found using pool, run, and eddy
39 habitats. Recent surveys of larval flannelmouth sucker in western Grand Canyon (Lava Falls to
40 Pearce Ferry) found the highest abundance of larvae in embayments, isolated pools, backwaters,
41 and other low-velocity habitats (Albrecht et al. 2014).

42
43
44 **Life History.** The flannelmouth sucker is an omnivorous benthic feeder, foraging on
45 invertebrates, algae, plant seeds, and organic and inorganic debris (Bezzerrides and Bestgen 2002;
46 Rees et al. 2005). Larvae feed primarily on aquatic invertebrates, crustaceans, and organic debris

1 (Childs et al. 1998). As they become juveniles and adults, their diet shifts and becomes primarily
2 composed of benthic matter including organic debris, algae, and aquatic invertebrates
3 (Rees et al. 2005).
4

5 This species has been reported to prefer water temperatures ranging from 10 to 27°C
6 (50 to 81°F), and is most common at about 26°C (79°F) (Sublette et al. 1990). Water
7 temperatures reported during spawning activity range from 6 to 18.5°C (43 to 65°F), but are
8 usually above 14°C (57.2°F) (Bezzerrides and Bestgen 2002). In the lower Colorado River Basin,
9 flannelmouth sucker spawning typically occurs in March and April (Bezzerrides and Bestgen
10 2002). Water temperature has been suggested as a primary cue for spawning in other parts of this
11 species range, but it does not appear to provide a spawning cue in Grand Canyon where
12 relatively synchronized spawning has been reported among sucker stocks from creeks with
13 different temperature and flow regimes (Weiss 1993; Weiss et al. 1998). In the Paria River, the
14 timing of spawning has been correlated with the receding limb of the hydrograph (Weiss 1993).
15

16 In Grand Canyon, flannelmouth suckers apparently spawn at only a limited number of
17 tributaries, and fish may move considerable distances to reach spawning sites (Douglas and
18 Marsh 1998; Weiss et al. 1998; Douglas and Douglas 2000). Tributary spawning in the Grand
19 Canyon may be timed to take advantage of warm, ponded conditions at tributary mouths that
20 occur during high flows in the mainstem Colorado River (Bezzerrides and Bestgen 2002).
21

22 Body condition of flannelmouth sucker is variable throughout Grand Canyon, but is
23 greatest at intermediate distances from Glen Canyon Dam, possibly because of the increased
24 number of warmwater tributaries in this reach (Paukert and Rogers 2004). Mean condition peaks
25 during the prespawn and spawning periods, and is lowest in summer and fall
26 (McKinney et al. 1999; Paukert and Rogers 2004). Sucker condition in September was positively
27 correlated with Glen Canyon discharge during summer (June–August), possibly due to an
28 increased euphotic zone and greater macroinvertebrate abundance observed during higher water
29 flows (Paukert and Rogers 2004).
30
31

32 **Factors Affecting Distribution and Abundance in the Grand Canyon.** Flannelmouth
33 sucker populations have declined throughout the species' historic range; in the lower Colorado
34 River, this decline has been attributed primarily to flow manipulation and water development
35 projects (Rees et al. 2005). Coldwater releases from Glen Canyon Dam have altered the thermal
36 regime of the main channel of the Colorado River, which for larvae may result in slow growth,
37 delayed transition to the juvenile stage, and possibly higher mortality (Rees et al. 2005).
38

39 In the cold tailwaters below Glen Canyon Dam, water temperatures (8 to 12°C [46 to
40 54°F]) are at the lower end of or below those needed for spawning and recruitment of
41 flannelmouth suckers; even though water temperatures do warm downstream, the cold summer
42 water temperatures have been suggested as a major factor limiting survival of young-of-the-year,
43 recruitment, and condition of this species in the main channel (Thieme et al. 2001;
44 Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in
45 the 1990s and then increased after 2000; the largest recruitment estimates were for 2003 and
46 2004, when there was a sudden increase in mainstem water temperatures because of warmer

1 releases from Glen Canyon Dam (Walters et al. 2012). Paukert and Rogers (2004) reported post-
2 spawn condition of flannelmouth sucker below Glen Canyon Dam to be variable, but were
3 typically greatest in the vicinity of warm water tributaries such as the Paria River, the Little
4 Colorado River, and Bright Angel Creek.

5
6 The flannelmouth sucker in the Grand Canyon may also be experiencing competition
7 with and predation by nonnative species that are in the system (Rees et al. 2005). Potential
8 competitors include species such as the channel catfish and the common carp. Potential predators
9 include rainbow and brown trout and red shiner. Rainbow and brown trout diet sampling found
10 enough juvenile flannelmouth suckers in trout stomachs to account for as much as 50% of the
11 estimated annual mortality rates of juveniles (Yard et al. 2011; Walters et al. 2012). The ability
12 of flannelmouth sucker to escape trout predation is also inhibited by colder water temperatures
13 (Ward and Bonar 2003).

14 15 16 **Speckled Dace**

17
18 The speckled dace is native to the western United States, and is one of eight species in the
19 genus *Rhinichthys*. It is a small fish, typically less than 76 mm in length, and has a relatively
20 short lifespan of about 3 years (Sigler and Sigler 1987).

21
22
23 **Distribution and Abundance.** This species is native to all major western drainages from
24 the Columbia and Colorado Rivers south to Mexico (AZGFD 2002c). Within the Grand Canyon,
25 this species occurs within the mainstem Colorado River and its tributaries, including the Little
26 Colorado River (Robinson et al. 1995; Ward and Persons 2006; Makinster et al. 2010). Long-
27 term fish monitoring of the Colorado River below Glen Canyon Dam since 2000 shows the
28 speckled dace to be the third most common fish species (and most common native species) in the
29 river between Glen Canyon Dam and the Lake Mead inflow, and it was captured most commonly
30 in western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010).

31
32
33 **Habitat.** The speckled dace may be found in a variety of habitats, ranging from cold,
34 fast-flowing mountain streams to warm, intermittent desert streams and springs. Where found, it
35 occurs in rocky runs, riffles, and pools of headwater streams, creeks, and small to medium rivers,
36 typically in waters with depths less than 1.6 ft (AZGFD 2002c); it rarely occurs in lakes (Page
37 and Burr 1991).

38
39
40 **Life History.** The speckled dace is an omnivorous bottom feeder, feeding primarily on
41 insect larvae and other invertebrates, as well as algae and fish eggs. Its young are mid-water
42 plankton feeders (Sigler and Sigler 1987). This dace spawns twice, once in spring and again in
43 late summer (AZGFD 2002c). Spawning occurs over gravel in areas prepared by the male.

1 **Factors Affecting Distribution and Abundance in the Grand Canyon.** The speckled
2 dace is a widespread and abundant species in western North America (AZGFD 2002c). Although
3 this species is the most widely distributed and abundant native fish species in the Grand Canyon
4 ecosystem, its abundance and distribution could be affected by many of the same factors that
5 affect the abundance and distribution of the other native fish in the ecosystem, namely altered
6 temperature, flow, and sediment regimes and predation by nonnative fish (AZGFD 2002c; Gloss
7 and Coggins 2005).
8
9

10 **3.5.3 Nonnative Fish**

11
12 As many as 25 nonnative species of fish have been reported with some regularity from
13 Lakes Powell and Mead and the Colorado River and its tributaries between these lakes (Valdez
14 and Speas 2007; Coggins et al. 2011; Reclamation 2011e; Table 3.5-2). Most of these introduced
15 species are native to other basins in North America but not the Colorado River Basin, and a few
16 are species from outside North America. These fish occur in the Grand Canyon as a result of
17 intentional and unintentional introductions, especially into Lakes Powell and Mead. A number of
18 species were stocked as game fish and others as forage fish for the stocked game fish. Among
19 these nonnative species, three are largely restricted to Lake Powell and/or Lake Mead, and occur
20 in the Colorado River and its tributaries below Glen Canyon Dam only occasionally; these
21 species are black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and
22 gizzard shad (*Dorosoma cepedianum*) (Table 3.5-2). Another four species—northern pike
23 (*Esox lucius*), threadfin shad (*Dorosoma petenense*), rock bass (*Ambloplites rupestris*), and
24 yellow perch (*Perca flavescens*)—are largely restricted to the upper Little Colorado River
25 watershed (Ward and Persons 2006; Valdez and Speas 2007). The remaining 18 species have
26 been reported from the mainstem Colorado River and/or its tributaries between Glen Canyon
27 Dam and the inflow to Lake Mead. New introductions of nonnative fish species continue to be
28 documented throughout the Colorado River Basin, and new introductions are likely to occur
29 (Martinez et al. 2014).
30

31 Common nonnative fish species in Lake Powell include striped bass, smallmouth and
32 largemouth bass, walleye (*Sander vitreus*), bluegill, green sunfish (*Lepomis cyanellus*), common
33 carp, and channel catfish. Species that occur in the reservoir, but that are mainly associated with
34 tributaries and inflow areas, include fathead minnow, mosquitofish (*Gambusia affinis*),
35 red shiner, and plains killifish (NPS 1996; Reclamation 2007a). Largemouth bass
36 (*Micropterus salmoides*) and black crappie populations were stocked initially and, following
37 successful establishment, these were the principal target species in the sport fisheries for many
38 years. Both species have declined in recent years due to a lack of habitat structure for young fish.
39 Filling and fluctuation of the reservoir resulted in changing habitat that eliminated most of the
40 vegetation favored by many species (Reclamation 2007a). Smallmouth bass
41 (*Micropterus dolomieu*) and striped bass (*Morone saxatilis*) were introduced following these
42 changes in habitat structure and are presently the dominant predators in the reservoir
43 (Reclamation 2007a). Threadfin shad were introduced to provide an additional forage base and
44 quickly became the predominant prey species (NPS 1996). Gizzard shad were accidentally
45 introduced into Morgan Reservoir in the San Juan River drainage in 1996 and subsequently
46 proliferated in Lake Powell (Mueller and Brooks 2004; Vatland and Budy 2007).

1 **TABLE 3.5-2 Nonnative Fish Found in Colorado River through Glen and Grand Canyons**

Species	Native Origin	Occurrence in Project Area
<i>Coldwater Species</i>		
Rainbow trout (<i>Oncorhynchus mykiss</i>)	North America	Colorado River from Glen Canyon Dam to Havasu Creek; abundant from Glen Canyon Dam to Lees Ferry; abundance decreases through Marble Canyon to the confluence with the Little Colorado River, although substantial numbers may still be present in some locations in some years; locally abundant at the Little Colorado River confluence and some locations through Grand Canyon in some years.
Brown trout (<i>Salmo trutta</i>)	Europe	Colorado River from Glen Canyon Dam to Kanab Creek; locally abundant near confluence with Bright Angel Creek, the Little Colorado River, and some other tributaries.
<i>Warmwater Species</i>		
Black bullhead (<i>Ictalurus melas</i>)	North America	Lake Powell, Lake Mead; Colorado River at the Little Colorado River; Colorado River downstream of Diamond Creek; generally absent from Glen Canyon, rare in Marble Canyon, and locally common in some areas of the Grand Canyon.
Yellow bullhead (<i>Ameiurus natalis</i>)	North America	Colorado River downstream of the Little Colorado River to Lake Mead; Little Colorado River, abundance presumed similar to that of black bullhead.
Channel catfish (<i>Ictalurus punctatus</i>)	North America	Lake Powell, Lake Mead, Colorado River from Marble Canyon to Lake Mead; generally absent from Glen Canyon, rare in Marble Canyon, and numerous in the Grand Canyon.
Green sunfish (<i>Lepomis cyanellus</i>)	North America	Lake Powell; Lake Mead; Kanab Creek; discovered in abundance in a slough located just downstream of Glen Canyon Dam in 2015 (eradication efforts conducted); generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Bluegill (<i>Lepomis macrochirus</i>)	North America	Lake Powell, Lake Mead; abundance presumed similar to that identified for green sunfish.
Largemouth bass (<i>Micropterus salmoides</i>)	North America	Lake Powell; Kanab Creek; Lake Mead to Maxson Canyon; generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Smallmouth bass (<i>Micropterus dolomieu</i>)	North America	Lake Powell; Colorado River at the Little Colorado River, below Glen Canyon Dam; rare from Glen Canyon through the Grand Canyon.

2

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Rock bass (<i>Ambloplites rupestris</i>)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Black crappie (<i>Pomoxis nigromaculatus</i>)	North America	Lake Powell; Lake Mead; generally absent from Glen Canyon, Marble Canyon, and Grand Canyon.
Fathead minnow (<i>Pimephales promelas</i>)	North America	Colorado River from the Paria River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Golden shiner (<i>Notemigonus crysoleucus</i>)	North America	Colorado River from Glen Canyon to Separation Canyon; Kanab Creek; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Redside shiner (<i>Richardsonius balteatus</i>)	North America	Lake Powell; Colorado River at the Little Colorado River; generally rare throughout Glen Canyon, Marble Canyon, and Grand Canyon.
Red shiner (<i>Cyprinella lutrensis</i>)	North America	Colorado River at the Little Colorado River; Colorado River from Bridge Canyon to Lake Mead.
Common carp (<i>Cyprinus carpio</i>)	Eurasia	Lake Powell, Lake Mead, Colorado River from Glen Canyon Dam to Lake Mead.
Goldfish (<i>Carassius auratus</i>)	Eurasia	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Plains killifish (<i>Fundulus zebrinus</i>)	North America	Little Colorado River; Colorado River from Little Colorado River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Mosquitofish (<i>Gambusia affinis</i>)	North America	Lake Powell; Colorado River from Separation Canyon to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Walleye (<i>Stizostedion vitreum</i>)	North America	Lake Powell; Colorado River from Lava Falls to Lake Mead; generally rare throughout Glen Canyon (but consistently observed during electrofishing surveys), Marble Canyon, and the Grand Canyon.
Yellow perch (<i>Perca flavescens</i>)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Striped bass (<i>Morone saxatilis</i>)	North America	Lake Powell; Colorado River from Havasu Creek to Lake Mead; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Northern pike (<i>Esox lucius</i>)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Gizzard shad (<i>Dorosoma cepedianum</i>)	North America	Lake Powell; generally absent from Glen Canyon, Marble Canyon, and the Grand Canyon.
Threadfin shad (<i>Dorosoma petenense</i>)	North America	Lake Powell; Lake Mead; Colorado River from Glen Canyon to Separation Canyon; Upper Little Colorado River watershed; generally rare in Glen Canyon, Marble Canyon, and the Grand Canyon.

Sources: Holden and Stalnaker (1975); Gloss and Coggins (2005); Valdez and Speas (2007); Coggins et al. (2011); Reclamation (2011e).

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Common nonnative fish species present in Lake Mead include striped bass, largemouth bass, red shiner, common carp, threadfin shad, and mosquitofish. The sport fishery in Lake Mead is primarily for striped bass and largemouth bass, although catfish species and hatchery-reared rainbow trout are also targeted by some anglers (Reclamation 2007a). As with Lake Powell, nonnative fish species present in Mead were established through intentional and unintentional introductions.

Water released from Glen Canyon Dam is relatively cold and clear, as it is withdrawn from deep within Lake Powell (Table 3.5-3). Following construction of the dam, water release temperatures have typically ranged from 7 to 11°C (45 to 52°F). This results in river temperatures that are substantially cooler in summer and fall than those that occurred prior to construction of the dam. During periods of the year with warmer air temperatures, water temperatures gradually warm with downstream distance from the dam. These low water temperatures generally do not support native fish reproduction in the mainstem, and largely restrict native fish spawning to warmwater tributaries (Vernieu et al. 2005; Kennedy and Ralston 2011). Cold water similarly limits growth rates and reproduction for many of the warmwater nonnative fishes present in the mainstem (Clarkson and Childs 2000). However, low reservoir elevations since 2003 have resulted in release temperatures as high as 16°C (61°F) in some years. Table 3.5-3 presents average recorded water temperatures for various locations downstream of Glen Canyon Dam from 2006 to 2009.

The nonnative fish community changes in response to temperature and turbidity gradients in the mainstem (Makinster et al. 2010). In general, the reaches of the river just downstream of Glen Canyon Dam are dominated by coldwater nonnative species while downstream reaches

1 **TABLE 3.5-3 Mean Water Temperature and Turbidity for Selected Sites in the**
 2 **Colorado River Mainstem from 2006 to 2009**

Mainstem River Location	Mean Water Temperature (°C±SD [°F±SD])	Turbidity (NTU) ^a
Lees Ferry, RM 0	10.4 ±1.5 (50.7 ±2.7)	2 ±10.5
Fence Fault, RM 30	10.7 ±1.5 (51.3 ±2.7)	50 ±347
Upstream Little Colorado River Confluence, RM 61	11.3 ±1.7 (52.3 ±3.0)	71 ±478
Phantom Ranch, RM 88	12.0 ±2 (53.5 ±3.6)	225 ±672
Diamond Creek Vicinity, RM 225	13.8 ±3.1 (56.9 ±5.5)	347 ±1,070

^a NTU = nephelometric turbidity units. As NTU increases, water clarity decreases.

Source: Kennedy and Ralston (2011).

3
 4
 5 through Grand Canyon are currently dominated by native species, although substantial numbers
 6 of warmwater nonnative species are also present (Makinster et al. 2010). The water temperatures
 7 in the Glen Canyon reach are suitable (although colder than optimal) for rainbow trout spawning
 8 and growth (McKinney, Speas et al. 2001). In the reach of cool, clear water between the dam and
 9 the Little Colorado River, the productivity of the aquatic food web (Section 3.5.1) is driven by
 10 microscopic algae (Angradi 1994; Shannon et al. 1994), invertebrate biomass is higher than in
 11 reaches further downstream (Stevens, Shannon et al. 1997), and rainbow trout (a visual sight
 12 feeder) is the dominant fish species (Makinster et al. 2010). As water temperature and turbidity
 13 increase downstream of the Little Colorado River confluence, nonnative warmwater fish species
 14 such as the common carp, red shiner, and several species of catfish increase in number
 15 (Makinster et al. 2010). The warmer water temperatures provide suitable conditions for spawning
 16 and growth for many of the warmwater nonnative species, many of which are benthic feeders
 17 adapted to foraging in turbid conditions (Gloss and Coggins 2005).

18
 19 In addition, the annual distribution of nonnative fishes in the lower portions of Grand
 20 Canyon may also be influenced by the elevation of Lake Mead. As the elevation of Lake Mead
 21 rises, lake-like conditions suitable for many of the warmwater nonnative fishes will temporarily
 22 extend farther upstream into the lower portion of the Grand Canyon.

23
 24 More detailed information on coldwater and warmwater nonnative fish species is
 25 provided in the next two sections.

26
 27
 28 **3.5.3.1 Coldwater Nonnative Species**
 29

30 Brown and rainbow trout make up the coldwater nonnative fish community of the
 31 Colorado River between Glen Canyon Dam and the inflow to Lake Mead (Figure 3.5-1). The
 32 rainbow trout is common in the Lees Ferry reach and in the mainstem Colorado River between
 33 the confluence with the Paria River and the confluence with the Little Colorado River

1 (Makinster et al. 2010; Reclamation 2011e). Smaller numbers are found associated with
2 tributaries, including Bright Angel Creek, Shinumo Creek, Deer Creek, Tapeats Creek, Kanab
3 Creek, and Havasu Creek (Reclamation 2011e). Brown trout are found primarily in and near
4 Bright Angel Creek, which supports a spawning population (Reclamation 2011e), but they are
5 also found throughout the upper reaches of the river corridor, including in Glen Canyon.
6
7

8 **Rainbow Trout**

9

10 The rainbow trout is very common in the reach of the mainstem Colorado from Glen
11 Canyon Dam to the Paria River, and this population serves as the principal basis for the trout
12 fishery. This species is also found in relatively high abundance in Marble Canyon between the
13 Paria River and the confluence of the Colorado River with the Little Colorado River
14 (Makinster et al. 2010; Reclamation 2011e). Downstream of the Little Colorado River
15 confluence, smaller numbers of rainbow trout are found in localized aggregations associated with
16 some tributaries.
17

18 Rainbow trout were initially introduced in the Grand Canyon region through stocking of
19 tributaries such as Bright Angel Creek during the 1920s. Additional introductions of rainbow
20 trout were made downstream of Glen Canyon Dam in 1964 following completion of
21 construction. Prior to 1991, the population was maintained through annual stocking, and stocking
22 continued through 1998 (Makinster et al. 2011). Since that time, the Glen Canyon trout fishery
23 has been maintained through natural reproduction of rainbow trout rather than through stocking,
24 and, with the exception of localized spawning in some downstream tributaries, most of the
25 rainbow trout production in the Colorado River downstream of Glen Canyon Dam occurs within
26 the Glen Canyon reach. Collections of young-of-the-year rainbow trout during recent surveys in
27 the vicinity of the Little Colorado River suggest that some successful spawning may be occurring
28 in or near the Little Colorado River. Standardized annual monitoring of the population of
29 rainbow trout in the 15-mi reach of the Colorado River between Glen Canyon Dam and Lees
30 Ferry began in 1991. Based on catches of rainbow trout during annual monitoring surveys, the
31 abundance of rainbow trout in Glen Canyon generally increased over the period from 1991 to
32 1997, remained at high levels until approximately 2001, and then declined to low levels by 2007
33 (Figure 3.5-6). From 2008 through 2010, the relative abundance of rainbow trout in the Glen
34 Canyon reach again increased to near historic high levels. Relative abundance reached all-time
35 high levels in water years 2011 and 2012, followed by a decline in water year 2013 consistent
36 with previous high abundance estimates (AZGFD data as reported in GCMRC 2014;
37 Figure 3.5-6).
38

39 Rainbow trout recruitment and population size within the Glen Canyon reach appear to
40 be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999; McKinney,
41 Speas et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman,
42 Kaplinski et al. 2011; Korman et al. 2012). McKinney et al. (1999) attributed the increase in
43 abundance from 1991 to 1997 to increased minimum flows and reduced fluctuations in daily
44 discharges resulting from implementation of interim flows between 1991 and 1996 and adoption
45 of the current modified low fluctuating flow regime in 1996. The decline in abundance from
46 2001 to 2007 has been attributed to the combined influence of increased trout metabolic demands

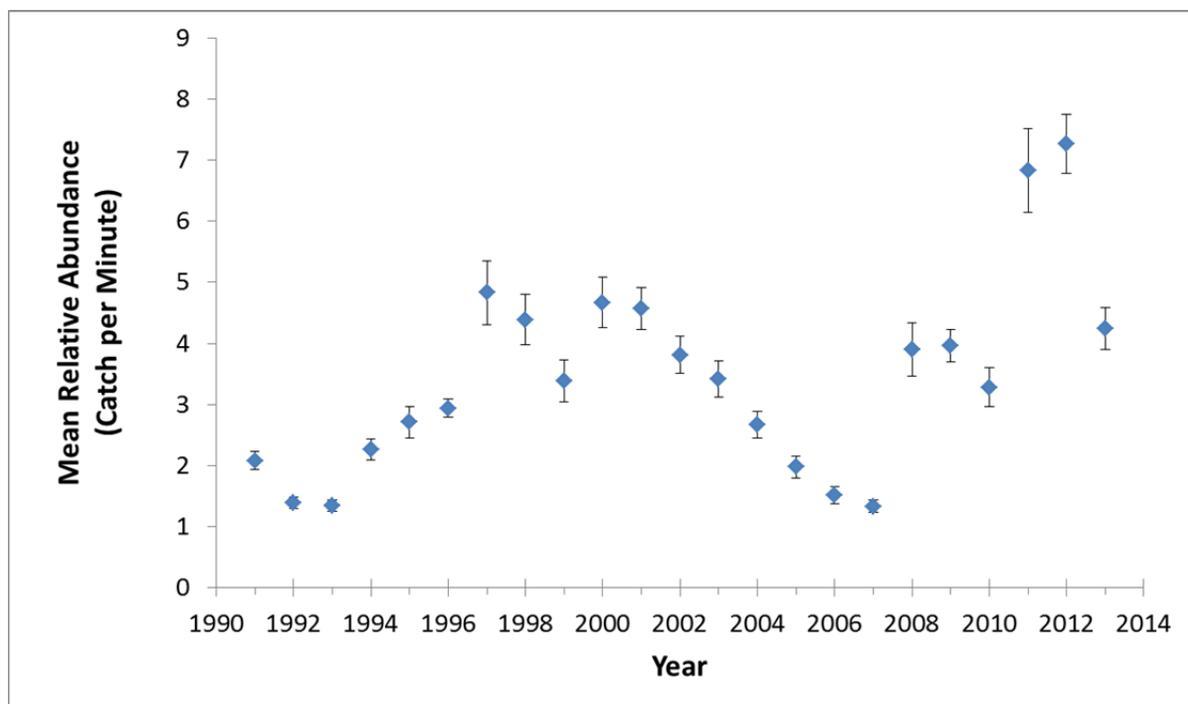


FIGURE 3.5-6 Mean (± 2 SE) Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2013 (Source: Persons 2014)

due to warmer water releases from Glen Canyon Dam during that period, together with a static or declining food base, periodic DO deficiencies, and high numbers of the invasive New Zealand mudsnail, which serves as a poor food source (Behn et al. 2010). A similar decline in rainbow trout abundance below the Paria River was observed during the 2001 to 2007 time period (Makinster et al. 2010). Increases in recruitment levels and the levels of trout abundance in the Glen Canyon reach during 2008 and 2009 are believed to be due to improved habitat conditions and survival rates for young-of-the-year rainbow trout resulting from the HFE that occurred in March of 2008 (Makinster et al. 2011). Korman et al. (2012) also found that recruitment of rainbow trout in Glen Canyon was positively and strongly correlated with annual flow volume and reduced hourly flow variation, and also that recruitment increased after two of three high-flow releases related to the implementation of equalization flows. The abundance of rainbow trout within the Glen Canyon reach affects the condition (a measure of the weight-length relationship, or “plumpness”) of rainbow trout in the population, with the condition generally being inversely related to the relative abundance of rainbow trout within the reach (Makinster et al. 2011). Thus, it has generally been observed that as the relative abundance of trout within the reach increases, the condition of trout within the reach declines; as condition falls lower, it is anticipated that survival and recruitment to the population would be affected.

Rainbow trout in Glen, Marble, and Grand Canyons are considered exposed to whirling disease. Whirling disease infects only salmon and trout species, and is caused by *Myxobolus cerebralis*, a myxozoan parasite introduced to North America from Europe in the 1950s. Whirling disease was initially detected in Glen Canyon in 2007 (Makinster 2007). Twenty-two

1 percent of rainbow trout samples collected from Glen Canyon in 2011 were found to be infected
2 with whirling disease. The presence of whirling disease has raised concerns regarding the
3 potential to spread whirling disease to unaffected waters and watersheds through live removal
4 and relocation of rainbow trout associated with the Nonnative Fish Control Environmental
5 Assessment (EA) (Reclamation 2011e). It is anticipated that there is a low risk of spreading
6 whirling disease as a consequence of conducting experimental floods as part of the High-Flow
7 Experiment EA (Reclamation 2011d; VanderKooi 2012). The parasite is already present
8 downstream from Glen Canyon Dam, and no barriers exist to prevent infected rainbow trout
9 from moving into Marble and Grand Canyons. It is likely that HFEs will result in a decrease in
10 the prevalence and severity of infections through reductions in the abundance of the intermediate
11 host, the oligochaete worm *Tubifex tubifex*, and its preferred habitat of fine sediment and organic
12 matter (VanderKooi 2012).
13

14 Because of the potential for trout to compete with and prey on native fish (Gloss and
15 Coggins 2005; Yard et al. 2011; Whiting et al. 2014), the numbers of trout that leave the Glen
16 Canyon reach and move to downstream locations is of potential concern. In particular, there is
17 interest in limiting the numbers of trout that would enter the reach of the Colorado River in the
18 vicinity of the confluence with the Little Colorado River because of the potential for negative
19 effects on the endangered humpback chub population (Gloss and Coggins 2005;
20 Yard et al. 2011). Data suggests that the numbers of trout that emigrate downstream from the
21 Glen Canyon reach may largely be driven by the abundance of trout within the Glen Canyon
22 reach. An increase in rainbow trout in the Little Colorado River reach after 2006 has been
23 attributed to the increased survival and growth of young trout in the Glen Canyon reach
24 following the March 2008 HFE (Wright and Kennedy 2011). The largest increases in trout
25 abundance in both the Glen Canyon reach and the vicinity of the confluence with the Little
26 Colorado River were seen after the 2011 equalization flows (Figure 3.5-6). It has been suggested
27 that the 2008 HFE may have improved conditions for spawning and egg incubation of rainbow
28 trout in the Glen Canyon reach by flushing fine sediment from spawning gravels and may have
29 improved the survival of young trout by increasing the production and availability of
30 invertebrates that serve as food for trout (Korman et al. 2010; Rosi-Marshall et al. 2010;
31 see Section 3.5.1 for background information on the aquatic food base). Modeling conducted by
32 Korman et al. (2012) suggests that 70% or more of the variation in the rates of rainbow trout
33 emigration from the Glen Canyon reach could be explained by variation in recruitment levels in
34 the Glen Canyon reach. Regardless, higher recruitment does not necessarily result in greater
35 levels of emigration and there are years in which recruitment levels in the Glen Canyon reach
36 were relatively high but emigration into Marble Canyon was not (e.g., following the HFE in
37 2012; Korman et al. 2012). In addition to emigration of trout to the Little Colorado River reach,
38 recent captures of young-of-the-year trout upstream of the Little Colorado River confluence
39 suggest that there may be some limited amount of spawning in lower Marble Canyon. Efforts to
40 control nonnative fish in the Little Colorado River reach using flow manipulation to limit
41 recruitment in Glen Canyon and mechanical removal in the Little Colorado River reach itself are
42 described in Section 3.5.3.4.
43
44

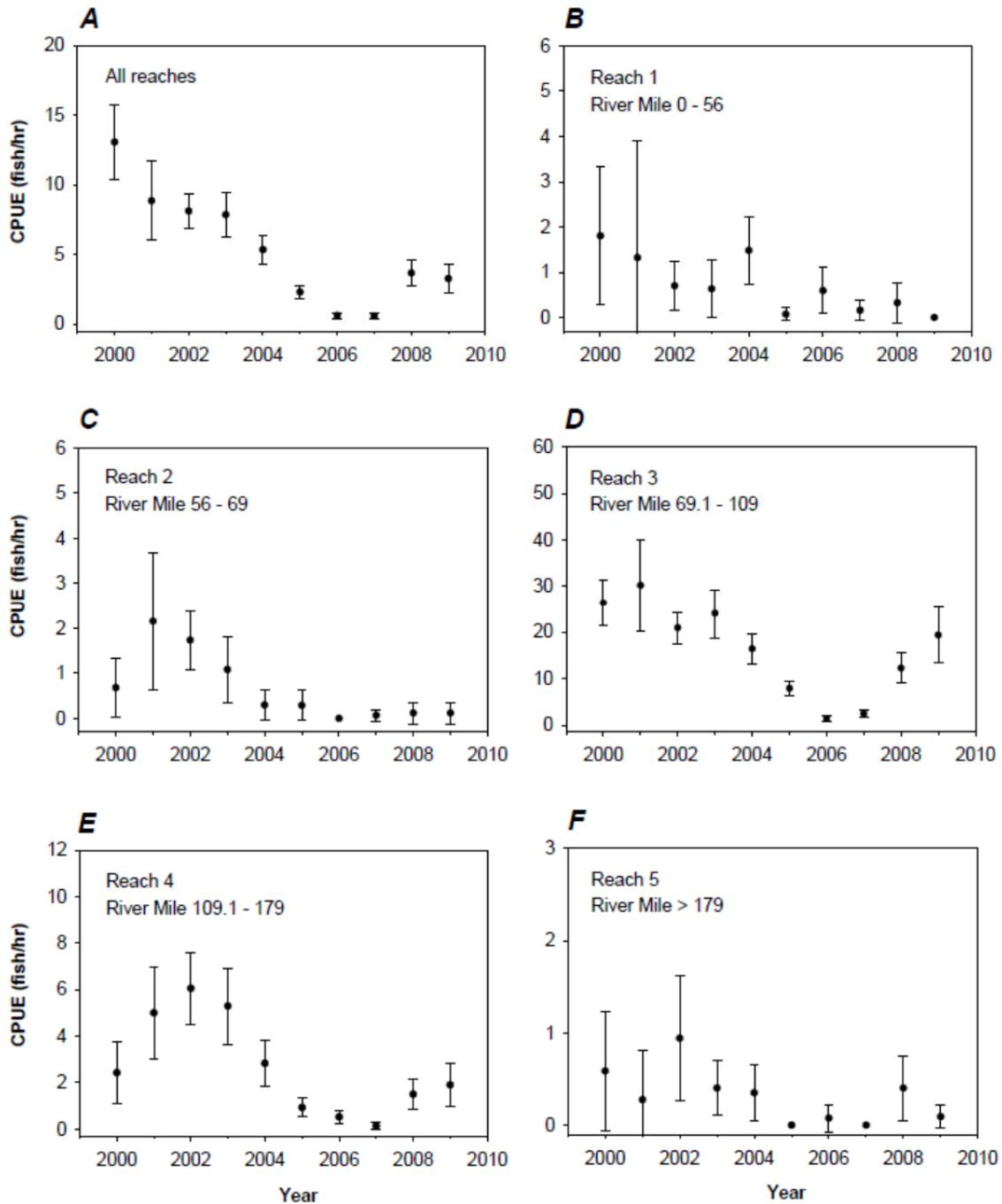
1 **Brown Trout**
2

3 As with rainbow trout, brown trout are not native to the Colorado River and were stocked
4 in Grand Canyon in the first half of the 1900s. Brown trout are no longer stocked in the Colorado
5 River downstream of Glen Canyon Dam and are now found primarily in and near Bright Angel
6 Creek, which supports a naturally spawning population (Reclamation 2011e). Unlike rainbow
7 trout, brown trout are not susceptible to infestations of whirling disease. A trout control project,
8 using a combination of a fish weir trap and electrofishing to benefit native species in Bright
9 Angel Creek and endangered humpback chub in the Colorado River, was implemented by the
10 NPS during winters 2006–07, 2010–11, 2011–12, 2012–13, 2013–14, and 2014-15 under the
11 2006 and 2013 EAs and a Finding of No Significant Impact (FONSI; NPS 2006c, 2013d).
12

13 Overall, the abundance (based on electrofishing surveys) of brown trout in the Colorado
14 River between Lees Ferry and Lake Mead declined from 2000 to 2006; abundance may have
15 increased somewhat between 2007 and 2009 (Figure 3.5-7; Makinster et al. 2010). Because
16 spawning by brown trout in the Grand Canyon occurs primarily in tributaries (e.g., Bright Angel
17 Creek and Shinumo Creek), recruitment rates may be less affected by conditions in the mainstem
18 than recruitment rates of rainbow trout. Mainstem spawning and recruitment may be limited
19 because of unsuitable temperatures, competition from rainbow trout, and limited availability of
20 suitable habitat for spawning and rearing of young fish.
21

22 Some brown trout captured in Bright Angel Creek were originally tagged in other parts of
23 the Colorado River, as much as 25 mi from Bright Angel Creek (Reclamation 2011e). Small
24 numbers of brown trout are also found in other locations within Grand Canyon, including in the
25 vicinity of the Little Colorado River confluence and in Glen Canyon. An indication of the
26 relative abundance of brown and rainbow trout in the vicinity of the Little Colorado River is
27 provided by the numbers captured using electrofishing during trout removal efforts. Of
28 23,000 nonnative fish captured as part of removal efforts from 2003 to 2006, 19,020 were
29 rainbow trout and 470 were brown trout (Reclamation 2011e). All brown trout captured during
30 these efforts were removed from the river.
31

32 Although the number of brown trout is small relative to rainbow trout, Yard et al. (2011)
33 found that on an individual basis, the brown trout is a more active predator on native fish in the
34 Colorado River than rainbow trout (see Section 3.5.3.3). Yard et al. (2011) also found a
35 significant positive correlation between temperature and the levels of piscivory by brown trout.
36 Other studies have indicated that water temperature may influence the susceptibility of native
37 fish to predation from brown and rainbow trout in different ways. For example, while the
38 incidence of predation attempts increased, the success of predation of rainbow trout on
39 young-of-the-year humpback chub decreased as temperatures increased from 10°C to 20°C (50°F
40 to 68°F) (Ward 2011). In contrast, the success of predation by brown trout did not change
41 significantly over the same temperature range (Ward 2011).
42
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FIGURE 3.5-7 Mean (± 2 SE) Electrofishing Catch Rates of Brown Trout in the Colorado River between Lees Ferry and Lake Mead, 2000–2009 (Note differences in scale among graphs A–F.) (Source: Makinster et al. 2010)

1 **3.5.3.2 Warmwater Nonnative Species**
2

3 Surveys of the Colorado River and its tributaries between Glen Canyon Dam and the
4 inflow to Lake Mead, as well as experimental fish removal studies, indicate the presence of
5 17 nonnative warmwater fish species (Trammell and Valdez 2003; Ackerman et al. 2006;
6 Makinster et al. 2010; Coggins et al. 2011; Albrecht et al. 2014) (Table 3.5-2). Among the
7 species collected, the common carp, fathead minnow, and red shiner are generally the most
8 common warmwater species in the mainstem and tributaries (Rogers and Makinster 2006; Ward
9 and Rogers 2006; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011). Smaller
10 warmwater nonnative species, such as fathead minnow, red shiner, plains killifish, and bullhead,
11 are primarily found in tributaries, especially in the Little Colorado River, but may also be found
12 in the mainstem below the Little Colorado River confluence (Johnstone and Lauretta 2007).
13

14 Warmwater nonnative species have been collected in low numbers and only sporadically
15 in the Glen Canyon reach; species collected include the common carp, channel catfish, and
16 fathead minnow (Johnstone and Lauretta 2007; Ackerman 2008). Other species collected from
17 this reach include green sunfish, smallmouth bass, striped bass, redbelt shiner, golden shiner, and
18 walleye (FWS 2008). During July 2015, a large, reproducing population of green sunfish was
19 discovered in a slough at RM 12, approximately 3 mi downstream of Glen Canyon Dam. Neither
20 the source nor mechanism of introduction for some of these species (e.g., green sunfish,
21 smallmouth bass) into the Glen Canyon reach is known with certainty; however, the nearest
22 source for a number of these species is Lake Powell.
23

24 Warmwater nonnative species collected from the mainstem Colorado River in the vicinity
25 of the Little Colorado River confluence include smallmouth and striped bass, green sunfish,
26 black and yellow bullhead, red shiner, and plains killifish (Trammell and Valdez 2003;
27 Johnstone and Lauretta 2007; FWS 2008).
28

29 Based on surveys conducted below Diamond Creek (RM 226–276.5) in 2005, the most
30 abundant nonnative fish species included red shiner, mosquitofish, channel catfish, and common
31 carp (Ackerman et al. 2006). Albrecht et al. (2014) reported that native fishes composed
32 approximately 98% of the total age-0 catch during 2014 surveys and dominated the total number
33 of small-bodied fish captured during 2013–2014 surveys in lower Grand Canyon (Lava Falls to
34 Pearce Ferry); bluehead sucker, flannelmouth sucker, and speckled dace were the most common
35 native species collected. Eight nonnative species were captured during 2013–2014 surveys,
36 including brown trout, rainbow trout, common carp, channel catfish, fathead minnow, plains
37 killifish, western mosquitofish, and red shiner (Albrecht et al. 2014). Bridge Canyon Rapid
38 (RM 235.1) may provide a natural impediment to the upstream movement of many of the
39 nonnative fish except striped bass, walleye, and channel catfish (Valdez and Leibfried 1999;
40 Reclamation 2011a).
41

42 The Little Colorado River may represent a source for some nonnative fishes found in the
43 mainstem Colorado River (Stone et al. 2007). As many as 20 species of warmwater nonnative
44 fishes have been reported from the Little Colorado River watershed (Table 3.5-4). Warmwater
45 species collected from the Little Colorado River below Chute Falls include common carp, red
46 shiner, fathead minnow, plains killifish, black bullhead, and channel catfish (Table 3.5-3) (Ward

1
2
3

TABLE 3.5-4 Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed^{a,b}

Species	Below Chute Falls	Above Chute Falls
Black bullhead	X	X
Yellow bullhead	X	X
Common carp	X	X
Channel catfish	X	X
Green sunfish	X	X
Fathead minnow	X	X
Plains killifish	X	X
Red shiner	X	X
Threadfin shad	–	X
Goldfish	–	X
Golden shiner	–	X
Northern pike	–	X
Mosquitofish	–	X
Rock bass	–	X
Bluegill	–	X
Smallmouth bass	–	X
Largemouth bass	–	X
Black crappie	–	X
Yellow perch	–	X
Walleye	–	X

^a X = present; – = absent.

^b Fish reported from below and above Chute Falls within the 21-mi perennially flowing portion of the Little Colorado River corridor.

Sources: Ward and Persons (2006); Stone et al. (2007).

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and Persons 2006; FWS 2008). Standardized monitoring from 1987 to 2005 found that nonnative warmwater fish generally comprise only a small percentage of the fish collected from the Little Colorado River, typically accounting for less than 10% of the total fish catch in any single year (Ward and Persons 2006). Six species of warmwater nonnative fish (common carp, fathead minnow, red shiner, channel catfish, yellow bullhead, and plains killifish) are known to reproduce in the Little Colorado River (Choudhury et al. 2004).

Climatologists predict that the Southwest will experience extended drought due to global climate change, and lower Lake Powell Reservoir elevations and warmer release temperatures are predicted (Seager et al. 2007; CCSP 2008a,b). Warmer water conditions could benefit warmwater nonnative fishes, result in invasions of new species, and cause greater proliferation of existing nonnative fish species (Rahel and Olden 2008).

1 **3.5.3.3 Interactions with Native Species**
2

3 Nonnative fish in the Colorado River are considered to adversely affect native fish in the
4 system through predation and/or competition, and by serving as hosts for parasites
5 (Minckley 1991; Coggins et al. 2002, 2011; Gloss and Coggins 2005; Olden and Poff 2005).
6
7

8 **Predation and Competition.** Piscivory by rainbow and brown trout has been suggested
9 as a large source of mortality for native fish in the Colorado River and its tributaries below Glen
10 Canyon Dam (Blinn et al. 1993; Marsh and Douglas 1997; Yard et al. 2011; Whiting et al. 2014).
11 Near the confluence of the Little Colorado River, Yard et al. (2011) found that 90% of the
12 vertebrate prey consumed by rainbow and brown trout were fish and estimated that rainbow and
13 brown trout consumed over 30,000 fish in the vicinity of the Little Colorado River during a
14 2-year study period. The incidence of piscivory (proportion of individuals feeding on fish) by
15 species was 70% for brown trout and only up to 3.3% for rainbow trout. However, rainbow trout
16 were approximately 50 times more abundant during the study period, and it was estimated that
17 they accounted for more than half of the total number of fish consumed in the study area
18 (Yard et al. 2011). Overall, trout ate 85% more native fish than nonnative fish, even though
19 native fish comprised less than 30% of the small fish available as prey in the study area. Of
20 ingested fish that were identifiable, 56% was comprised of native fish, while another 28.8% was
21 composed of unidentified suckers (presumably native flannelmouth and bluehead suckers). Of
22 the identified native fish consumed by the trout, about 27% were humpback chub, 15% were
23 speckled dace, 11% were flannelmouth sucker, and 3% bluehead sucker (Yard et al. 2011).
24 Because the majority of humpback chub consumed by trout during the study were young-of-the-
25 year and subadults (<3 years), predation on such fish could affect recruitment to the humpback
26 chub population in the Grand Canyon (Coggins and Walters 2009; Yard et al. 2011). Because of
27 differences in the levels of piscivory exhibited by brown and rainbow trout, current decisions to
28 implement removal actions at the Little Colorado River to benefit humpback chub are triggered
29 by levels of both brown trout and rainbow trout present in the reach, as well as consideration of
30 the status (estimated size) of the humpback chub population.
31

32 In the Grand Canyon, brown trout, rainbow trout, channel catfish, and black bullhead are
33 considered the primary predators of humpback chub, while common carp are a major humpback
34 chub egg predator in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997;
35 FWS 2008). Fathead minnow, red shiner, and plains killifish may be important predators and
36 competitors of young humpback chub, especially in the Little Colorado River (Marsh and
37 Douglas 1997; Valdez and Ryel 1997; FWS 2008). Marsh and Douglas (1997) examined
38 predation of native fish by nonnative fish in the Little Colorado River and found rainbow and
39 brown trout, channel catfish, and black and yellow bullhead to be predators of native fish. In
40 stomachs from these species that contained food, native fish comprised about 14% of the
41 ingested materials, and ingested species included humpback chub, speckled dace, and bluehead
42 and flannelmouth suckers. Whiting et al. (2014) evaluated diets of rainbow and brown trout from
43 Bright Angel Creek, another tributary of the Colorado River in the Grand Canyon, and found that
44 native fish (primarily speckled dace) comprised approximately 4% of the diet for larger rainbow
45 trout and 19% of the diet for larger brown trout.
46

1 While trout predation on humpback chub has been demonstrated, it is uncertain whether
2 or not trout piscivory has had (or has) a population-level effect on the humpback chub
3 (Yard et al. 2011). Although survival and recruitment of humpback chub have increased
4 following trout removal in 2003 and 2004, it is not known if this increase is due to trout removal
5 or other environmental factors, and further experimentation would be needed to tease apart other
6 system-level dynamics that could have contributed to adult humpback chub population increases
7 observed since 2000. For example, the temperature of water released from Glen Canyon Dam
8 increased during the trout removal study period to temperatures that may have improved
9 humpback chub growth and survival (Coggins et al. 2011). Ongoing studies have indicated that
10 water temperature may influence the susceptibility of native fish to predation from brown and
11 rainbow trout (e.g., Ward 2011; Ward and Morton-Starner 2015; see Section 3.5.3.1).

12
13 In addition to predation, nonnative fish may affect native fish through competition for
14 resources that may be limited, such as food or appropriate habitat. Many of the small-bodied fish
15 (including juveniles of larger species) in the Colorado River downstream of Glen Canyon Dam
16 share similar habitats and food items, thereby increasing the potential for resource competition.
17 For example, nonnative fathead minnows are likely to compete with juvenile bluehead and
18 flannelmouth suckers for resources, since they occupy the same habitat types and also have a
19 high degree of overlap in the types of food items eaten (Seegert 2010). Diet evaluations and
20 stable isotope analyses for fish from Bright Angel Creek found that the diets of rainbow trout and
21 small (<150 mm total length) brown trout overlap with native fishes, suggesting competition for
22 food resources (Whiting et al. 2014). Although the magnitude of species-level effects among the
23 various native and nonnative species is poorly understood in most cases, it is likely that such
24 competition has an effect on the abundance and survival of native species.

25
26 Research on the food web dynamics of the Grand Canyon provides further evidence that
27 competition between native fish and nonnative fishes is likely occurring. Invertebrates, primarily
28 blackflies and midges, are important food items for both humpback chub and nonnative fishes,
29 particularly rainbow trout. Throughout Marble and Grand Canyons, invertebrate production is
30 low, and fishes consume most of this production. Cross et al. (2013) hypothesized that an influx
31 of rainbow trout from upstream coupled with this limited resource base may lead to strong
32 competition among fishes in the Grand Canyon, and that dam operations that alter fish
33 populations such as HFEs may exacerbate this effect.

34
35
36 **Parasites and Diseases.** The introduction and establishment of nonnative fish in the
37 Colorado River below Glen Canyon Dam has also resulted in the introduction of several species
38 of fish parasites that have the potential to adversely affect native fishes in the system
39 (Clarkson et al. 1997; Choudhury et al. 2004). Whirling disease, which affects rainbow trout but
40 not the other native or nonnative species in the Colorado River below Glen Canyon Dam, was
41 discussed above. The Asian tapeworm and the anchor worm have been found in native and
42 nonnative warmwater fish in the Colorado River and its tributaries below Glen Canyon Dam, and
43 the prevalence of these parasites is especially high in the Little Colorado River
44 (Clarkson et al. 1997; Choudhury et al. 2004). For example, since first being identified from
45 humpback chub in the Little Colorado River in 1990, reported infestation rates of the Asian
46 tapeworm in native fish in the Little Colorado River were over 50% in some life stages of the

1 humpback chub and as much as 60% in juvenile speckled dace (Clarkson et al. 1997). A 2-year
2 seasonal study of fish parasites in the Little Colorado River reported 17 species of parasites from
3 four native and seven nonnative fish (Choudhury et al. 2004).
4

5 The effects of parasite infestation may be serious. For example, pathological effects of
6 the Asian tapeworm have been reported to include intestinal abrasion and disintegration, as well
7 as blockage and perforation of the gastrointestinal tract; chronic effects may include reduced
8 growth and reproductive capacity, depressed swimming ability, and secondary bacterial
9 infections (Clarkson et al. 1997). Fish larvae infested with the anchor worm may be killed, if
10 vital organs are penetrated by the anchors, and secondary infections are possible at attachment
11 points (Berry et al. 1991).
12

13 The effects of many of the parasites that have been reported for other fish species suggest
14 that these parasites have the potential to adversely affect native fishes in the Colorado River
15 below Glen Canyon Dam. The high prevalence of parasites in native and nonnative fish in the
16 Little Colorado River may be especially of concern, given the importance of the Little Colorado
17 River in the reproduction of the humpback chub and maintenance of the humpback chub
18 population in the Colorado River below Glen Canyon Dam.
19

20 The potential for expansions and infestations of nonnative parasites may also be
21 influenced by water temperatures. Rahel and Olden (2008) suggested that climate change could
22 facilitate expansion of nonnative parasites. This may be an important threat to humpback chub.
23 Optimal Asian tapeworm development occurs at 25–30°C (77–86°F) (Granath and Esch 1983),
24 and optimal anchorworm temperatures are 23–30°C (73–86°F) (Bulow et al. 1979). Coldwater
25 temperatures in the mainstem Colorado River in Marble and Grand Canyons have likely
26 prevented these parasites from completing their life cycles and limited their distribution. Warmer
27 climate trends or operational alternatives could result in warmer overall water temperatures,
28 thereby increasing the prevalence of these parasites, which can weaken humpback chub and
29 increase mortality rates.
30
31

32 **3.5.3.4 Nonnative Fish Control Activities and Effects of Flow Conditions** 33

34 A number of management activities have been designed and implemented to test their
35 efficacy for controlling and reducing the abundance and distribution of nonnative fishes in the
36 Colorado River and its tributaries below Glen Canyon Dam. These control activities included
37 (1) flow releases from Glen Canyon Dam designed to reduce trout recruitment and
38 (2) mechanical removal of trout and warmwater nonnative fish in the vicinity of the Colorado
39 River–Little Colorado River confluence (Reclamation 2011e). A series of HFEs were conducted
40 in 1996, 2004, 2008, 2012, 2013, and 2014 to benefit sandbar resources, improve camping
41 beaches, and potentially improve the quality of shoreline habitats for native fish in Grand
42 Canyon National Park (Melis et al. 2010, 2012). Dodrill et al. (2015) reported that although
43 experimental floods increased the prevalence and extent of backwaters, the effects were modest
44 and would be expected to dissipate quickly. Although the 2008 spring HFE was not specifically
45 implemented to investigate the use of high flows for nonnative fish control, there was a large
46 increase in rainbow trout early life stage survival rates and the abundance of rainbow trout

1 following the HFE; whether such increases would be supported by future spring HFEs is unclear,
2 and the effects of fall HFEs on rainbow trout are less clear. The potential effects of HFEs on
3 trout are described below, as are the possible effects of equalization flows on trout.
4

6 **Nonnative Fish Suppression Flows**

7
8 Flows designed to reduce trout recruitment in Lees Ferry were tested in 2003–2005.
9 These flows, conducted from January through March, were intended to dewater and expose
10 rainbow trout redds in the Glen Canyon reach to lethal air temperatures for part of the day,
11 thereby reducing the survival of trout eggs in the exposed redds (Korman et al. 2005; Korman,
12 Kaplinski et al. 2011; Korman and Melis 2011). The flow regimes tested during this period
13 consisted of increasing the extent of daily flow variation during winter and early spring from the
14 normal range of 10,000–18,000 cfs in January and 7,000–13,000 cfs in February–March to a
15 range of 5,000–20,000 cfs in January–March; these operations also resulted in longer periods of
16 dewatering for redds at lower elevations than would occur under normal operations. The
17 fluctuating flows were determined to have resulted in increasing the incubation mortality rate
18 from 5–11% under normal flow conditions to 23–49% under fluctuating flows (Korman et al.
19 2005; Korman, Kaplinski et al. 2011; Korman and Melis 2011). However, no measurable
20 reduction in age-0 abundance was observed, presumably due to increased survival of those
21 rainbow trout that survived. These results suggest that the increased level of incubation mortality
22 did not exceed compensatory survival responses (Korman, Kaplinski et al. 2011). Because of
23 these results, it has been suggested (Korman, Kaplinski et al. 2011; Korman and Melis 2011) that
24 a more limited fluctuating flow regime may be effective, targeting juvenile trout after the
25 majority of density-dependent responses to egg incubation and hatching success has been
26 realized, but before age-0 trout leave habitats that are potentially more sensitive to flow
27 fluctuations. Testing flow regimes under which flow variation is increased during late spring and
28 summer months when small age-0 trout are utilizing potentially flow-sensitive, low-angle habitat
29 has been suggested (Korman et al. 2005; Korman and Melis 2011).
30

32 **Nonnative Fish Removal**

33
34 The removal of predatory nonnative fish has been conducted in various locations in the
35 upper and lower basins of the Colorado River since the mid-1990s with varying degrees of
36 success (Mueller 2005). Removal of nonnative fish in the Colorado River near the Little
37 Colorado River confluence was conducted from 2003 to 2006, and in 2009 (Korman et al. 2005;
38 Makinster et al. 2009; Coggins et al. 2011). Fish removal activities in 2003–2006 captured more
39 than 36,000 fish, of which 23,266 were nonnative species (including 19,020 rainbow trout)
40 (Korman et al. 2005; Coggins et al. 2011). The removal of trout was estimated to have reduced
41 rainbow trout abundance in this reach from about 6,500 in January 2003 to about 620 in
42 February 2006. Immigration and recruitment account for the difference between the number of
43 trout removed and the abundance estimates. During the 2003–2006 removal activities, large
44 increases in the abundance of fathead minnow and black bullhead were reported beginning in
45 September 2005, suggesting increases in immigration, survival, or both. The observed increase
46 may have been due to increased emigration from the Little Colorado River where these species

1 spawn, or because the combination of reduced rainbow trout numbers and increasing water
2 temperatures may have caused these species to be more abundant and susceptible to capture
3 (Coggins et al. 2011).
4

5 Coincident with the 2003–2006 removal activities, the humpback chub population
6 stabilized and increased, suggesting that the nonnative fish removal (especially the removal of
7 rainbow trout) may have allowed higher survival and recruitment by humpback chub (Coggins
8 and Walters 2009; Coggins et al. 2011). However, the relationship between trout removal and
9 survival of humpback chub is not clear because there was a system-wide decrease in rainbow
10 trout abundance and drought-induced increases in river water temperatures during the time of the
11 removal activities that could also have led to increased survival and recruitment of juvenile
12 native fish (Coggins et al. 2011). As indicated in Figure 3.5-3, stabilization and increases in the
13 adult humpback chub population may have begun as early as 2002, prior to the nonnative fish
14 removal actions. Because changes in the adult humpback chub population rely, in part, on
15 survival and recruitment of juvenile humpback chub, increases in survival rates may have
16 occurred for several years prior to the fish removal activities. Further, even though the
17 abundance of trout appeared to return to pre-removal levels by 2009, the estimated adult
18 abundance of humpback chub continued to increase (Figure 3.5-3)
19

20 Nonnative fish removal was also conducted in 2009, the results of which indicated that
21 rainbow trout abundance in the vicinity of the Little Colorado River had rebounded from the
22 declines observed in 2006–2007 (Coggins et al. 2011; Reclamation 2011a). The number of
23 rainbow trout in the vicinity of the Little Colorado River prior to the 2009 removal activities was
24 estimated to be similar to the high densities estimated in 2002 (prior to the 2003 fish removal
25 activities) (Wright and Kennedy 2011).
26

27 Nonnative fish removal is also being conducted in Shinumo and Bright Angel Creeks to
28 restore and enhance the native fish communities and to reduce predation and competition on
29 endangered humpback chub from nonnative fish. These removals are being conducted to
30 implement conservation measures identified in the 2008 Biological Opinion, the
31 2009 Supplement, and the 2011 Biological Opinion on the operation of Glen Canyon Dam
32 (FWS 2008, 2009; Reclamation 2011a). Nonnative fish (primarily rainbow trout) are being
33 removed from Shinumo Creek to minimize predation upon newly translocated humpback chub
34 and to reduce competition. From 2009 through 2014, 5,569 rainbow trout were removed from
35 Shinumo Creek using netting, angling, and electrofishing. Brown trout do not occur in Shinumo
36 Creek above a waterfall barrier near the mouth, but a few brown trout were removed below the
37 waterfall. Rainbow trout densities were reduced between summer 2011 and winter 2012, but
38 rebounded with a strong cohort in June 2012 (likely a “compensatory response”). Abundance of
39 bluehead sucker increased in the lower reaches downstream of translocation areas and speckled
40 dace increased throughout Shinumo Creek as rainbow trout densities were reduced. A sequence
41 of headwater fires and floods occurred in summer of 2014 that almost eliminated all nonnative
42 and native fish from Shinumo Creek. NPS plans to remove the remaining nonnative trout and
43 monitor the native fish. Nonnative fish, primarily rainbow trout, occur in small numbers in
44 Havasu Creek and are also removed when encountered (Healy et al. 2014).
45

1 From 2010 to 2012, trout reduction efforts in Bright Angel Creek included the installation
2 and operation of a fish weir trap and backpack electrofishing in the lower portion of the creek,
3 including the confluence of Bright Angel Creek to Phantom Creek. From 2012 to 2015, removals
4 were expanded to encompass the entire length of Bright Angel Creek (approximately 16 km) and
5 Roaring Springs (approximately 3 km). The operation of the weir was also extended from
6 October through February to capture greater temporal variability in the trout spawning migration.
7 From 2010 to December 2014, about 28,000 brown trout and 4,800 rainbow trout were removed
8 from Bright Angel Creek from both the weir and by electrofishing. Data on early 2015 removals
9 and native fish response are still being analyzed, but trout abundance appears to have been
10 reduced and native fish distribution has expanded upstream. These data are preliminary and may
11 change slightly with further analysis (Healy et al. 2014; Nelson et al. 2012, 2015). As determined
12 through consultation with Traditionally Associated Tribes and others, and consistent with the
13 Memorandum of Agreement between the NPS and the Arizona State Historic Preservation
14 Office, trout removed from the creeks were preserved and distributed for beneficial use through
15 human consumption, or for use by the Tribes for other purposes.
16

17 In July 2015, AZGFD biologists discovered an unusually large, reproducing population
18 of green sunfish in a backwater slough connected to the mainstem Colorado River approximately
19 3 mi downstream of Glen Canyon Dam. Although the downstream end of the slough is
20 connected to the main channel under the typical range of releases from Glen Canyon Dam, the
21 upstream end of the slough is isolated from the main channel except during high flows. Green
22 sunfish are known to be prolific, with a single female capable of producing up to 10,000 eggs.
23 Green sunfish are considered likely predators of small-bodied native fish and native fish eggs.
24 Biologists with the AZGFD, NPS, USGS, USFWS, and Reclamation have determined that green
25 sunfish pose a threat to native fish including the humpback chub. Two removal efforts using
26 electrofishing, seine netting, and trapping were conducted in August 2015, but failed to deplete
27 the population despite removing over 3,000 fish. Biologists from the NPS and AZGFD
28 constructed and installed a large block net at the downstream end of the main slough to minimize
29 the escapement of green sunfish. After analyzing alternative methods for control, the agencies
30 authorized a short-term targeted treatment of the slough with the fish toxin rotenone. Information
31 available as of mid-November 2015 indicates that the eradication efforts appear to have been
32 successful at controlling this population.
33

34 The Pueblo of Zuni has expressed concerns to the DOI that management actions
35 described above involving fish suppression flows and mechanical removal of nonnative fish are
36 considered by Zuni to be the taking of life without a beneficial use. The following text was
37 provided by the Pueblo of Zuni to explain the basis of this concern:
38

39 During the important Zuni migrations in Grand Canyon many culturally and historically
40 important events occurred. One such specific event occurred in Zuni history which
41 defines the Zuni's familial relationship to aquatic life and provides the fundamental basis
42 for the Zuni objection to the mechanical removal of fish from the confluence of the
43 Colorado and the Little Colorado rivers. In the late nineteenth century, Frank Hamilton
44 Cushing (1884, 1896, 1988) recorded this historical event as it was narrated to him by the
45 Zuni. Cushing labeled the event as the "Abode of the Souls" and the following is a
46 condensed version of that event:

1 Shortly after Emergence, men of the Bear, Crane, and Seed clans strode into the
2 red waters of the Colorado River and waded across. The men of the clans all
3 crossed successfully. The women travelling with the men carried their children on
4 their backs and they waded into the water. Their children, who were unfinished
5 and immature (because this occurred shortly after Emergence), changed in their
6 terror. Their skins turned cold and scaly and they grew tails. Their hands and feet
7 became webbed and clawed for swimming. The children fell into the swift, red
8 waters. Some of the children became lizards, others turned into frogs, turtles,
9 newts and fish. The children of these clans were lost to the water. The mothers
10 were able to make it to the other side of the river, where they wailed and cried for
11 their children. The Twins heard them, returned, and advised the mothers to
12 cherish their children through all dangers. After listening to the Twins, those
13 people who had yet to pass through the river took heart and clutched their children
14 to them and safely proceeded to the opposite shore. The people who successfully
15 made it out of the river rested, calmed the remaining children, and then arose and
16 continued their journey to the plain east of the two mountains with great water
17 between. Thence, they turned northward to camp on the sunrise slopes of the
18 uppermost mountains.

21 **High-Flow Experiments**

23 A number of HFEs have been conducted in the Colorado River below Glen Canyon Dam
24 (1996, 2004, 2008, 2012, 2013, 2014) to improve camping beaches and potentially improve the
25 quality of shoreline habitats for native fish in Grand Canyon National Park (Melis et al. 2010,
26 2012). Rainbow trout abundance was found to increase following the spring HFEs in 1996 and
27 2008 (Makinster et al. 2011; Kennedy and Ralston 2011). In particular, the 2008 cohort was the
28 largest on record up to that date, while the 2009 cohort was very strong compared to other years
29 (Korman, Kaplinski et al. 2011; Korman and Melis 2011). While fish hatched before and up to
30 one month after the HFE showed lower early survival rates, fish hatched more than one month
31 after the HFE showed a large increase in their early survival rate, with age-0 fish abundance
32 being four times higher than expected (Melis et al. 2010; Korman and Melis 2011).

34 It is thought that cohorts produced after the HFE were not exposed to high flows and
35 emerged into better quality habitat with better food availability (Rosi-Marshall et al. 2010).
36 Concentrations of invertebrate prey in the drift following the spring 2008 HFE showed some
37 prey items such as midge and blackflies (primary preferred food of rainbow trout) to have
38 increased as much as 400% to 800%, and elevated levels in the drift continued for as much as
39 15 months following the HFE (Melis 2011). The observed changes in rainbow trout abundance
40 following these two HFEs suggest that spring HFEs may benefit rainbow trout populations
41 (Kennedy and Ralston 2011).

43 In contrast to the increased abundance of rainbow trout following the spring HFEs in
44 1996 and 2008, trout abundance was reduced following the fall (November) HFE in 2004
45 (Kennedy and Ralston 2011). However, rainbow trout in the Glen Canyon reach were showing a
46 general population decline that started 2 years prior to the 2004 HFE, and, therefore, results in

1 uncertainty regarding the inferences about the influence of the fall 2004 HFE on rainbow trout
2 abundance and whether the response is different from those associated with spring HFEs.
3 Analyses of the influence of a fall HFE that occurred in 2012 on rainbow trout recruitment are
4 still underway, although the relative overall abundance of rainbow trout in the Glen Canyon
5 reach declined from 2012 to 2013 (Figure 3.5-6) due to declines in abundance of fish in smaller
6 size classes.

9 **Equalization Flows**

10
11 There is also a potential for the abundance of young-of-the-year rainbow trout to be
12 affected by the high, steady, and sustained flows that result from equalization flows required by
13 the Interim Guidelines to balance the volumes of water stored in Lake Powell and Lake Mead. A
14 substantial increase in numbers of age-0 trout was observed in 2011 following a period of
15 sustained high flows required for equalization (Korman, Persons et al. 2011). It has been
16 hypothesized that the high, steady flows associated with equalization operations could benefit
17 age-0 rainbow trout by inundating additional habitat for spawning, incubation of eggs, and
18 production of food resources. Implementation of equalization flows under the Interim Guidelines
19 is a separate action from LTEMP and would not be affected by LTEMP.

22 **3.6 VEGETATION**

23
24 Terrestrial plant communities along the Colorado River from Glen Canyon Dam to
25 Lake Mead are highly diverse due to great variations in land forms, geologic features, and
26 physical characteristics such as topography, elevation, and aspect. Plant communities along the
27 Colorado River are greatly influenced by flow characteristics.

30 **3.6.1 Historic and Remnant Riparian Plant Communities**

31
32 A natural riverine environment existed along the Colorado River corridor prior to the
33 modifications in flow regime and sediment transport that resulted from the construction of Glen
34 Canyon Dam (Turner and Karpiscak 1980). Conditions within riparian habitats were constantly
35 changing and highly unstable, with wide variations in annual flood flows as well as annual
36 periods of low flow (Clover and Jotter 1944; Turner and Karpiscak 1980). Seasonal floods,
37 averaging about 86,000 cfs but frequently exceeding 100,000 cfs (Johnson 1991), resulted from
38 snowmelt and spring rains; while sporadic floods from tributaries resulted from local storms,
39 particularly during the summer monsoon season. Flood flows provided soil moisture which
40 created opportunities for the establishment of species adapted to wet or moist soils near the river
41 across a highly variable range of stage elevation (Clover and Jotter 1944). Floods were also
42 sources of disturbance, removing plants by drowning or scouring across that elevation range
43 (Clover and Jotter 1944). While well-established willows in some locations of Lower Grand
44 Canyon could reach a height of 30 to 40 ft, these willows could be partially or completely
45 removed by floods (Clover and Jotter 1944). Vegetation was typically sparse in areas that were
46 frequently flooded; however, when a number of years passed between flood events, denser

1 growth could develop. In broader reaches of the canyon, scouring was somewhat diminished,
2 allowing some perennial plants to become established in sediment deposits near the river (Turner
3 and Karpiscak 1980).

4
5 A zone of riparian vegetation, referred to by NPS as the Old High Water Zone, was well
6 established just above the pre-dam scour zone (at and just above the approximately 100,000-cfs
7 stage elevation) (Carothers and Brown 1991). Following dam construction, annual high flows
8 have been limited to approximately 45,000 cfs or lower, except for four higher flow years
9 (1983–1986) since 1965. These relatively low annual high flows have permitted riparian
10 vegetation to develop below the Old High Water Zone in what has become known as the
11 New High Water Zone. Before the dam, annual high flows carried large sediment loads through
12 Glen and Grand Canyons, scouring nearly all vegetation below the Old High Water Zone
13 (Carothers and Brown 1991; Kearsley and Ayers 1999; Ralston 2005).

14
15 The principal species⁶ of the Old High Water Zone in Glen Canyon included
16 New Mexico olive (*Forestiera pubescens*), Apache plume (*Fallugia paradoxa*), and netleaf
17 hackberry (*Celtis reticulata*), and in Glen and upper Marble Canyons included apache plume,
18 netleaf hackberry, western redbud (*Cercis occidentalis*), live oak (*Quercus turbinella*), and
19 New Mexico olive. The Grand Canyon lacks the latter two species in the river corridor, and
20 catclaw acacia (*Acacia greggii*) and mesquite (*Prosopis glandulosa*) are dominant with desert
21 broom (*Baccharis sarothroides*) becoming important downstream from RM 127 (Spence 2006;
22 Carothers and Brown 1991; NPS 2005a). Pre-dam sediment terraces occupy the upper levels of
23 the Old High Water Zone and support species adapted to dry soil conditions. High terraces in
24 Glen Canyon support dense stands of four-wing saltbush (*Atriplex canescens*); however, in the
25 Grand Canyon, catclaw acacia, brittlebush (*Encelia* spp.), barrel cactus
26 (*Ferocactus cylindraceus*), bursage (*Ambrosia dumosa*), creosote (*Larrea divaricata*), ocotillo
27 (*Fouquieria splendens*), and other Mojave-Sonoran desert species also occur (Spence 2006).

28
29 Surfaces that were subject to frequent floods prior to dam construction ranged from
30 barren to sparsely vegetated (Turner and Karpiscak 1980). Some of the species that occurred
31 prior to the dam in this sparsely vegetated zone included tamarisk, also known as salt cedar
32 (*Tamarix* spp.); seepwillow (*Baccharis* spp.); arrowweed (*Pluchea sericea*); and coyote willow
33 (*Salix exigua*). Tamarisk, a species of Eurasian origin, was described in the 1930s as occurring
34 along the river in “thickets near the eastern end of the park,” “fringing the river near the mouth
35 of Bright Angel Creek” (Dodge 1936), and “along the river from Nankoweap Creek to the base
36 of Tanner Trail” (GCNHA 1936). Historic photos from Lees Ferry show tamarisk had
37 established by 1923 (Graf 1978). Clover and Jotter (1944) noted tamarisk occurred in scattered
38 locations (in moist sand near the river’s edge) along the length of the river except for a large
39 section of Marble Canyon; it was observed at and above Lees Ferry, below Vasey’s Paradise, at
40 the mouth of Saddle Canyon, Lava Pinnacle, and at Separation Rapids. Based on analyses of
41 pre-dam photographs, tamarisk probably occurred as widespread isolated individuals (Turner and
42 Karpiscak 1980).

⁶ Plant names in this section use the Flora of North America (FNA 2014) and TROPICOS (Tropicos 2014) nomenclatures.

3.6.2 Existing Riparian Vegetation Downstream from Glen Canyon Dam

The response of riparian vegetation to the operation of Glen Canyon Dam has been well studied, as summarized by Ralston (2012) and Sankey, Ralston et al. (2015). Most evidence indicates that riparian vegetation composition, structure, distribution, and function are closely tied to ongoing dam operations. “Riparian vegetation” includes all plants found within the Fluctuating, New High Water, Old High Water, and Pre-Dam Flood Terrace hydrologic zones of the mainstem Colorado River downstream from Glen Canyon Dam, as described below.

Following construction of Glen Canyon Dam and the regulation of flows, including the reduction in annual flood peaks and increased year-round water availability at lower stage elevations, riparian vegetation expanded into the newly stable habitat and increased substantially (Ralston 2010; Kennedy and Ralston 2011; Webb et al. 2011; Sankey, Ralston et al. 2015; Turner and Karpiscak 1980). The overall trend since completion of the dam has been the encroachment of New High Water Zone vegetation onto sandy beaches (Kearsley et al. 1994; Webb et al. 2002). At the same time, water availability decreased or was eliminated at higher elevations above the average annual daily maximum flows. The overall trend in the Old High Water Zone has been increased mortality of species such as mesquite and hackberry (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Plant communities present along the river have developed through associations of species with similar responses to moisture gradients, tolerance to water stress, and modes of reproduction (Kearsley et al. 2006; Stevens et al. 1995; Ralston et al. 2014; Ralston 2012). Such species associations occur on geomorphic surfaces of debris fan-eddy complexes, such as reattachment bars and separation bars, as well as on channel margins between these complexes, and respond dynamically to changes in flow characteristics. Geomorphic setting, substrate type/texture, hydrology, and species life history characteristics affect the temporal and spatial occurrence of plant communities (Ralston et al. 2014; Merritt et al. 2010). Because of historical patterns of dam releases, communities below the 25,000-cfs elevation on these surfaces differ somewhat from those above that level. Seven plant community types have been identified as occurring on these geomorphic surfaces (Ralston et al. 2014) and are given in Table 3.6-1.

Vegetation zones along the river reflect the frequency of inundation and disturbance (Ralston 2010, 2012; Kennedy and Ralston 2011). The Fluctuating Zone (Figure 3.6-1) supports flood-tolerant marsh species such as sedges, rushes, cattail, horsetail, and common reed. These species occupy return current channels and successional backwaters that are inundated daily for at least part of the year (i.e., up to the elevation of the average annual daily maximum discharge of about 20,000 cfs). The New High Water Zone lies within the influence of dam operations but above daily fluctuation levels (Carothers and Brown 1991). Vegetation in the Fluctuating and New High Water Zones are greatly influenced by river flow and dam operations (Stevens et al. 1995; Porter 2002; Kearsley and Ayers 1999; Kearsley et al. 2006; Ralston 2005, 2012).

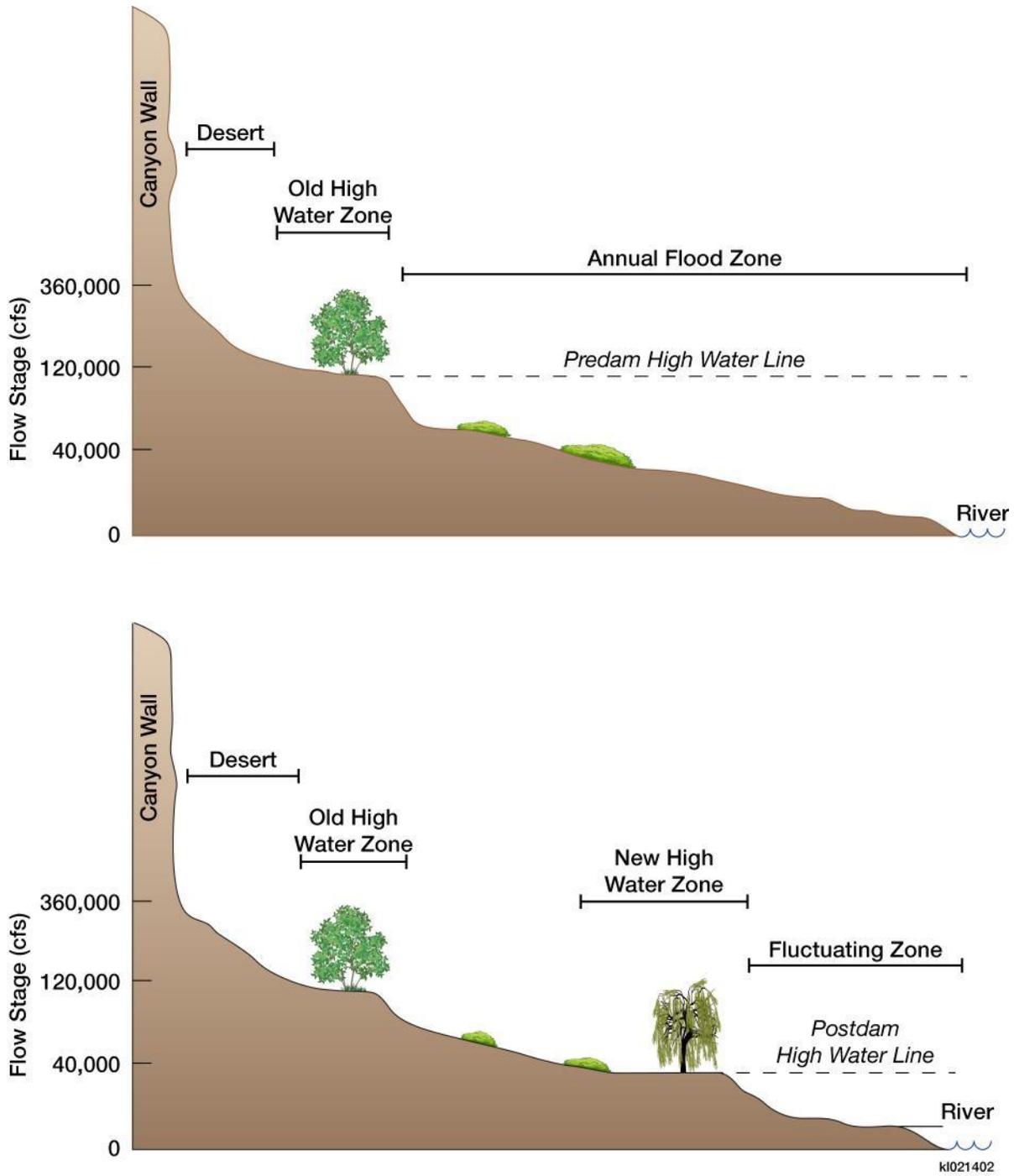
The New High Water Zone, inundated by flows up to 45,000 cfs, supports woody riparian species, many herbaceous obligate riparian species (e.g., *Carex* spp., *Juncus* spp., *Equisetum* spp., *Phragmites australis*, and *Typha* spp.) with bunchgrasses such as sand dropseed

1 **TABLE 3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and**
 2 **Channel Margins**

Plant Community	Dominant Species	Geomorphic Surfaces
Common reed temperate herbaceous vegetation	Common reed (<i>Phragmites australis</i>), cattail (<i>T. latifolia</i> , <i>T. domingensis</i>), common tule (<i>Schoenoplectus acutus</i>), creeping bent grass (<i>Polypogon viridis</i>)	Lower reattachment bar
Coyote willow-Emory seep willow shrubland/horsetail herbaceous vegetation	Coyote willow, Emory seepwillow (<i>Baccharis emoryi</i>), horsetail (<i>Equisetum laevigatum</i>), common three-square (<i>Schoenoplectus pungens</i>), common spike-rush (<i>Eleocharis palustris</i>), alkali muhly (<i>Muhlenbergia asperifolia</i>)	Lower channel margin, lower reattachment bar
Tamarisk temporarily flooded shrubland	Tamarisk; in Glen Canyon also desert broom	All surfaces
Cottonwood/coyote willow forest	Coyote willow, cottonwood (<i>Populus fremontii</i>), Goodding's willow (<i>Salix gooddingii</i>), seepwillow (<i>Baccharis salicifolia</i>), salt grass (<i>Distichlis spicata</i>), alkali muhly, common reed, horsetail (<i>Equisetum</i> spp.), rush (<i>Juncus</i> spp.), sedge (<i>Carex</i> spp.), Russian olive (<i>Elaeagnus angustifolia</i>), tamarisk, creepingbent grass (<i>Agrostis stolonifera</i>), sweet clover (<i>Melilotus</i> spp.)	Lower separation bar, lower channel margin
Arrowweed seasonally flooded shrubland	Arrowweed (<i>Pluchea sericea</i>) in pure stands, or with seepwillow (<i>Baccharis</i> spp.), mesquite, or coyote willow	Lower reattachment bar, upper separation bar, upper channel margin, upper reattachment bar
Mesquite shrubland	Mesquite (<i>Prosopis glandulosa</i> var. <i>torreyana</i>), with seepwillow (<i>Baccharis</i> spp.), arrowweed	Lower channel margin, upper separation bar, upper channel margin, upper reattachment bar
Bare sand	Less than 1% vegetation cover	All surfaces

Source: Ralston et al. (2014).

3
4
5



1
 2
 3
 4
 5

FIGURE 3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam (adapted from Reclamation 1995)

1 and shrubs such as spiny aster at upper elevations. The dominant woody species of the Glen
2 Canyon and Grand Canyon New High Water Zone scrub communities include tamarisk, coyote
3 willow, arrowweed, and seepwillow (*Baccharis* spp.), along with desert broom downstream from
4 RM 162 (Spence 2006). Wide, alluvial reaches have greater vegetation cover than narrow,
5 confined reaches (Kennedy and Ralston 2011).

6
7 The Old High Water Zone, above 60,000 cfs to approximately 200,000 cfs, supports
8 pre-dam drought-tolerant riparian species found in riparian and upland habitats, such as honey
9 mesquite, catclaw acacia, netleaf hackberry, Apache plume, New Mexico olive, and mountain
10 pepperweed (*Lepidium montanum*), along with desert species such as Mormon tea
11 (*Ephedra* spp.), prickly pear (*Opuntia* spp.), creosote, ocotillo, and brittlebush. Mortality of Old
12 High Water Zone plants is occurring, and some species such as mesquite and hackberry are no
13 longer recruiting in this zone because of the lack of sufficiently high flows and nutrient-rich
14 sediment inputs; however, mesquite and catclaw acacia are now recruiting in the New High
15 Water Zone (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011; Ralston 2005).
16 Because flows do not exceed 45,000 cfs with normal dam operations, the upper margins of this
17 zone are moving downslope, resulting in a narrowing of the zone. Desert species occupy pre-dam
18 flood terraces and windblown sand deposits above the Old High Water Zone.

19
20 Vegetation on the geomorphic surfaces along the river (below about the 45,000-cfs stage
21 elevation) has changed since construction of the dam as a function of river flows and climate
22 (precipitation), as well as a result of factors such as increased soil salinity and increased sand
23 coarseness (Carothers and Aitchison 1976; Kearsley et al. 2006; Sankey, Ralston et al. 2015).
24 Return channel-eddy complexes support many of the largest and better developed riparian
25 patches (Spence 2006). Fluvial marsh wetlands were scarce prior to the construction of the dam
26 and were associated only with perennial tributaries and springs (Webb et al. 2002); however,
27 widespread marsh development occurred following the reductions of spring floods, with the
28 number increasing downstream (Stevens et al. 1995). Of the 1,625 ac of riparian vegetation
29 mapped in the New High Water Zone, approximately 5 ac represent marshes, or about 0.3%
30 (because of the typically small size of fluvial marshes, they are underrepresented in the current
31 map, which has a minimum mapping unit of 0.5 ha). Areas mapped as wetland vegetation,
32 including cattails and common reed, in 2002 totaled roughly 10 ac (Ralston 2012; Kennedy and
33 Ralston 2012). Marsh communities are generally dominated by a few species, varying by soil
34 texture and drainage. Wet marsh communities occur on fine-grained silty loams on lower areas
35 of eddy complex sandbars that are frequently inundated and are dominated by cattail and
36 common reed. Loamy sands support an association of horseweed (*Conyza canadensis*),
37 knotweed (*Polygonum aviculare*), and Bermuda grass (*Cynodon dactylon*) (Carothers and
38 Aitchison 1976; Kearsley et al. 2006). Shrub wetland communities (with coyote willow, Emory
39 seep willow, and horsetail the dominant species) occur on sandy soils of reattachment bars and
40 channel margins, below the 25,000-cfs stage, that are less frequently inundated. Clonal wetland
41 species such as cattail, common reed, and willow are adapted to burial and regrowth and recover
42 after burial following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). On areas of
43 higher stage elevations, short-lived plant species such as longleaf brickellbush, brownplume
44 wirelettuce (*Stephanomeria pauciflora*), broom snakeweed (*Gutierrezia microcephala*),
45 brittlebush, and Emory seepwillow colonize recently disturbed surfaces (Bowers et al. 1997;
46 Webb and Melis 1996). While longer-lived species, such as Mormon tea, cactus (*Opuntia* spp.),

1 and catclaw acacia (*Acacia greggii*), are not as quick to colonize disturbed areas, they are
2 expected to continue to expand into lower stage elevations in the absence of disturbance. These
3 species are found on surfaces that have not been disturbed for 7 to 28 years.
4

5 The population of Goodding's willow along the river below Glen Canyon Dam appears
6 to have been affected by the reduction in flood flows on upper riparian terraces, has been in
7 decline, and either no longer occurs at or does not reproduce at two-thirds of the sites where it
8 previously existed (GCWC 2011; Mortenson et al. 2008). Along with the coarsening of
9 substrates, the lack of springtime recruitment floods threatens remaining stands; however, high
10 flows during the mid-1980s resulted in some establishment of Goodding's willow in the Grand
11 Canyon (Mortenson et al. 2012; Ralston 2012). Restoration of Goodding's willow and several
12 other native species has been a focus of NPS revegetation efforts.
13

14 Beavers (*Castor canadensis*) have reduced Goodding's willow within the canyon and
15 may influence the invasion of resultant open areas (as well as areas of coyote willow herbivory)
16 by tamarisk (Mortenson et al. 2008). Beavers may be more common along the river now due to
17 the increase in post-dam availability of woody plants (Turner and Karpiscak 1980). In addition,
18 Fremont cottonwood (*Populus fremontii*) recruitment along the river is nearly eliminated each
19 year by beaver foraging on cottonwood seedlings, and very few Fremont cottonwood occur along
20 the river below the dam (GCWC 2011).
21

22 Arrowweed, a dominant native woody species of both the Old and New High Water
23 Zones, is adapted to burial by sediments deposited by floods (Ralston 2012). This drought-
24 tolerant clonal species responds to burial by resprouting from roots, buried stems, and rhizomes,
25 and subsequent vegetative growth (Ralston 2012). Arrowweed has characteristics of a primary
26 colonizer and quickly occupies open sandbar areas. It spreads laterally by underground rhizomes
27 and is commonly found in dense monotypic stands with few individuals of other species
28 intermixed (Ralston et al. 2014), thereby reducing species diversity in areas occupied. Because
29 arrowweed interferes with meeting a management objective of open sand beaches in some areas,
30 the NPS has removed it from targeted campsites.
31

32 A number of nonnative plant species, many of which are invasive species, occur
33 throughout the riparian zone; among the most common species are tamarisk, camelthorn
34 (*Alhagi maurorum*), Russian thistle (*Salsola tragus*), riggut brome (*Bromus diandrus*), red or
35 foxtail brome (*Bromus rubens*), cheatgrass (*Bromus tectorum*), yellow sweetclover
36 (*Melilotus officinalis*), spiny sow thistle (*Sonchus asper*), Ravenna grass (*Saccharum ravennae*),
37 perennial peppergrass (*Lepidium latifolium*), and Bermuda grass (Reclamation 2011d;
38 NPS 2005a). Ralston concludes that operations since the 1996 Record of Decision (ROD;
39 Reclamation 1996) have facilitated the recruitment, establishment, and expansion of both native
40 and exotic plant species (e.g., tamarisk) throughout the river corridor. Furthermore, a recent
41 analysis of vegetation data collected by NPS staff from 2007 to 2010 demonstrated an overall
42 increase in exotic plant cover, particularly in the New High Water Zone (Zachmann et al. 2013).
43

44 Tamarisk, a shrub or small tree usually less than 20 ft in height, has long been the most
45 prominent of these invasive species. As noted above, tamarisk was present along the river long
46 before construction of Glen Canyon Dam. Tamarisk along the Colorado River is a hybrid of at

1 least two distinct species (including *T. ramosissima* and *T. chinensis*) (Ralston 2010). It has an
2 advantage over native species that require access to groundwater, such as cottonwood and
3 willow, in areas where salinities are elevated or where water tables are lowered
4 (Reclamation 2011b). Tamarisk plants accumulate salt on their leaf surfaces, which then
5 accumulates in the surface layer of soil from dropped leaves (Ladenburger et al. 2006). The
6 germination and establishment of native species can be adversely affected as surface soils
7 increase in salinity, which can occur particularly in the absence of annual flooding and scouring,
8 such as along regulated rivers.

9
10 High annual floods during the mid-1980s resulted in high tamarisk mortality, with
11 surviving tamarisk located on upper riparian zone terraces; however, those floods also resulted in
12 high levels of tamarisk establishment on elevations well above current river levels
13 (Mortenson et al. 2012). Tamarisk establishment can increase when flood flows coincide with
14 seed releases during spring and early summer (peaking in late May and early June); floods
15 outside of that period result in little tamarisk recruitment (Mortenson et al. 2012; Stevens and
16 Siemion 2012). Seedling survival is greatest when establishment is above the elevation of
17 subsequent floods (Mortenson et al. 2012).

18
19 The tamarisk leaf beetle (*Diorhabda* spp.) has had a marked impact on the ecology of
20 riparian zones in the Grand, Marble, and Glen Canyons in recent years. The beetle was
21 discovered in 2009 near Navajo Bridge and at RM 12 and several locations, including Lees
22 Ferry, in 2010; by 2011, it had become established along the Colorado River, occurring
23 discontinuously from Glen Canyon Dam to RM 213, but primarily upstream of RM 27 and from
24 RM 127 to RM 180, with an estimated 70% defoliation at some sites (Johnson et al. 2012).
25 Permanent monitoring plots established in 2010 near Lees Ferry show evidence of mortality in
26 smaller individuals, plus defoliation rates of 75 to 100%. By late 2012, the tamarisk leaf beetle
27 was widely distributed in the Grand Canyon. The splendid tamarisk weevil (*Coniatus* spp.) also
28 occurs in the Grand Canyon, but much less is known about its abundance, distribution, and
29 impacts. The beetle causes early and repeated defoliation of tamarisk during the summer months
30 (Snyder et al. 2010; Hultine et al. 2010), which may eventually result in mortality after several
31 successive years of defoliation. The long-term effects of the tamarisk leaf beetle and splendid
32 tamarisk weevil on tamarisk abundance and distribution in Glen and Grand Canyons are
33 currently not known; however, plant communities in which tamarisk is currently a dominant
34 species will likely undergo compositional change (Shafroth et al. 2005). The extent of mortality
35 within a tamarisk stand varies by site and may not be extensive; tamarisk may persist despite
36 annual defoliation and may fluctuate with beetle populations (Nagler et al. 2012; Nagler and
37 Glenn 2013). Both native and nonnative plant species may become established on sites of
38 tamarisk mortality, although native species establishment may be slow, and future community
39 composition and habitat characteristics would depend on a variety of site-specific factors,
40 including site hydrology and microclimate, changes in nutrient dynamics, available seed
41 sources, and active restoration efforts (Belote et al. 2010; Hultine et al. 2010; Shafroth,
42 Merritt et al. 2010; Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012;
43 Bateman et al. 2013).

44
45 Past flow regimes and past flow experiments provide evidence for the types and scale of
46 potential impacts on vegetation from dam operations. The dynamics of large daily fluctuations

1 on vegetation are known from dam operations prior to 1991. Large daily fluctuations increase the
2 wetted area and thus the sandbar area available for colonization by wetland species; however,
3 erosion exacerbated by fluctuations may limit the available bar area (Stevens et al. 1995).
4 Increases in mean daily flow and daily inundation may remove low stage elevation vegetation
5 and coarsen soil texture. Daily fluctuations also flatten vegetation within the range of fluctuating
6 flows, export leaf litter, and coat leaf surfaces with silt (Stevens et al. 1995).

7
8 As a result of interim flows and MLFF, riparian vegetation moved into newly exposed
9 areas and a shift to more upland species in most New High Water Zone vegetation patches was
10 observed in Marble Canyon and Grand Canyon (Kearsley and Ayers 1996). The reduction of
11 daily inundation frequency may increase colonization of wet marsh species at low stage
12 elevations and promote the transition of higher elevation cattail/reed marshes to
13 tamarisk/arrowweed vegetation (Stevens et al. 1995).

14
15 As noted above, riparian vegetation communities can be affected by dam operations
16 through scouring and erosion during high flows, drowning, burial by new sediments, and
17 reductions in soil moisture levels; consistent availability of water at low elevations (e.g., below
18 25,000 cfs) from elevated base flows can promote vegetation growth. Responses of riparian
19 vegetation are affected by the timing, frequency, duration, and magnitude of the river's
20 hydrology, as well as the variability between years and sequencing of flows (Ralston et al. 2014;
21 Merritt et al. 2010). Additional factors related to flow that influence riparian vegetation include
22 characteristics of deposited sediments (such as water-holding capacity, aeration, and nutrient
23 levels), depth to groundwater, and anoxia in the root zone (Merritt et al. 2010). Flood flows
24 during the mid-1980s resulted in a reduction of more than 50% in woody riparian vegetated area
25 below the 60,000-cfs stage elevation due to scouring and drowning, with shallow-rooted species,
26 such as coyote willow, Emory seepwillow, and longleaf brickellia, experiencing the highest
27 mortality (Ralston 2012). The export of sediments (particularly silts and clays and organic
28 matter) coarsened substrates, affected nutrient concentrations, and reduced opportunities for
29 subsequent recruitment of tamarisk and native shrubs, such as coyote willow and Emory
30 seepwillow (Ralston 2012).

31
32 HFEs up to 45,000 cfs rework and rebuild riparian vegetation substrates on sandbars,
33 rocky slopes, debris fans, and return-current channels (Kennedy and Ralston 2011). HFEs also
34 make alluvial groundwater more available to plants growing near and above the 45,000 cfs stage
35 elevation (see Section 4.6.2.1). Seed germination is generally maximized with damp-soil or
36 shallow-water conditions. Floods enhance species diversity, reset successional stages, and
37 prevent monocultures in marsh and wetland habitats, and periodic flooding and drying in
38 wetlands is beneficial to diversity and productivity (Reclamation 2011d; Stevens et al. 1995).
39 Following the first HFE in 1996, total vegetative cover on sandbars was reduced approximately
40 20%, but there was no significant change in wetland or woodland/shrubland area 6 months later
41 (Kearsley and Ayers 1999). Vegetation may return quickly to sandbars following HFEs;
42 herbaceous plant cover doubled within 6 months after the 2008 HFE, and clonal wetland plants
43 such as common reed quickly established on sandbars and shorelines after the 1996 and
44 2008 HFEs (Kennedy and Ralston 2011). Over the period of controlled floods (since 1996), the
45 long-term trend for vegetation on low stage-elevation sandbars has been one of rapid expansion
46 in spite of the HFEs (Sankey, Ralston et al. 2015).

1 HFEs may result in minor short-term scouring of plants in the river channel and return
2 current channel marsh communities followed by a rapid recovery, generally in around 6 months
3 (Reclamation 2011b). HFEs, however, do not remove higher elevation vegetation (above
4 20,000 cfs; Ralston 2010). A September 2000 habitat maintenance flow of 31,000 cfs removed
5 57% of tamarisk seedlings, while native flood-adapted species increased, potentially by
6 vegetative reproduction (Porter 2002; Ralston 2011). Although some near-shore wetland plants
7 were removed by the 1996 and 2008 HFEs, woody riparian plants were not (Kennedy and
8 Ralston 2011). Very little change occurred in a Glen Canyon cattail/sedge marsh as a result of
9 the 1996 HFE (Spence 1996). Minor increases in the height and cover of vegetation were
10 observed, along with the appearance of three nonnative species that may have been dispersed by
11 the HFE.

12
13 Low-elevation grass and shrub species in marshes in Marble Canyon and Grand Canyon
14 may become buried with coarse sediment, followed by recovery within 6 to 8 months
15 (Reclamation 2011b). Coyote willow, seepwillow, tamarisk, and some low-lying grasses and
16 forbs were partially or completely buried by sediment during the 1996 and 2008 HFEs (Kennedy
17 and Ralston 2011). Many wetland species are adapted to burial and regrowth; some, such as
18 cattail, common reed, and willow, thrived after burial following the 1996 HFE (Kearsley and
19 Ayers 1999), and coyote willow recovered quickly after the 2008 HFE (Kennedy and
20 Ralston 2011). Burial during HFEs may favor such species and alter the riparian community
21 structure (Kennedy and Ralston 2011). Soil seed banks can be reduced, as following the
22 1996 HFE when approximately 45% of the seeds and 30% of the species richness of seeds
23 available for germination in near-surface soils was lost, due primarily to burial under sediment
24 (Kearsley and Ayers 1999). Coarsening of sand grain size on sandbars as a result of sequential
25 HFEs tends to favor clonal species such as arrowweed, coyote willow, and common reed
26 (Reclamation 2011b).

27
28 Although tamarisk has increased throughout the riparian corridor since construction of
29 the dam, HFEs do not necessarily result in the spread of tamarisk. The 1996 and 2008 HFEs
30 occurred in spring before tamarisk seed production. Tamarisk seedling establishment was
31 uncommon following both HFEs (Kennedy and Ralston 2011; Kearsley and Ayers 1999).
32 Tamarisk seedling establishment could be higher if HFEs occur during the time of seed
33 production (Mortenson et al. 2012); however, native species such as willows can also benefit
34 from HFEs during their seed production period (Kennedy and Ralston 2011). There was no
35 evidence of spread of camelthorn, another nonnative riparian species, in study sites after the
36 1996 HFE (Kennedy and Ralston 2011; Kearsley and Ayers 1999).

37
38 Low steady flows have been shown to have effects on vegetation. Low steady flows can
39 isolate some marsh patches and cause them to dry out (NPS 2005a). Mortality of horsetail at
40 higher elevations above the water table was 55% during low steady flows in June through
41 August of 2000 (Porter 2002). Those flows, which were preceded by higher spring flows, also
42 resulted in prolific tamarisk seedling establishment on recently exposed sandbars at low and
43 intermediate elevations in the Grand Canyon due to water availability and lack of competition
44 (Porter 2002; Ralston 2011; Mortenson et al. 2012). Seedling production of native riparian
45 species would have occurred prior to (willows) or later than (arrowweed, mesquite, and
46 seepwillow [*Baccharis* spp.]) the low steady flows (Ralston 2011). Native plants also became

1 established in low elevation areas, but at a slower rate than tamarisk, potentially by vegetative
2 reproduction (Porter 2002; Ralston 2011).

3 4 5 **3.6.2.1 Tribal Perspectives on Vegetation** 6

7 Vegetation plays an important role in the traditional cultural ties maintained by
8 indigenous peoples within the Canyons. The American Indian Tribes with the closest ties to the
9 Canyons have all identified culturally important plants in the Canyons. For example, plants are
10 perceived by the Zuni as a vital part of the landscape and are sacred to the Zuni people. All
11 plants were given to the Zuni by the ancestral, celestial, supernatural beings. The Zuni view all
12 plants as the offspring of Mother Earth because it was she who gave the plants to the Zuni
13 (Stevenson 1993). Native plants at *Chimik'yana'kya'de'a* are especially sacred as a result of their
14 association with the Zuni emergence and migration. Zuni fraternities and esoteric groups
15 consider these plants significant because of their past and present cultural importance and usage.
16 Today, these plants are collected and used for ceremonial, religious, subsistence, and medicinal
17 purposes.
18

19 Zunis use literally hundreds of plants for medicinal, cultural, or religious purposes.
20 Stevenson (1914) documented 123 plants being used for various purposes. This amount vastly
21 underestimates the true number of plants and their respective uses, because not all the uses of all
22 plants are known to all Zuni people. General plant usage for consumption or other everyday use
23 is commonly known to most Zunis. However, knowledge about some plants may be possessed
24 only by the members of a particular religious or medicine society, and in some cases specific
25 esoteric uses may be known only by a particular Zuni individual. Plants played key roles in
26 aiding the Zuni during their search for the middle place, as recounted in the Zuni emergence and
27 migration narrative.
28

29 Zunis continue to rely on medicinal plants, herbs, fetishes, and other remedies that have
30 served them through the ages. Camazine (1978) identified nearly 100 plants still used by Zunis
31 for medical treatments. As a result of four previous monitoring trips through the Grand Canyon,
32 the Zuni religious leaders preliminarily identified 32 plants of cultural importance in the spring
33 during which these trips were taken; however, medicinal plants and plants with religious
34 importance can be gathered as well during the other three seasons (winter, fall, and summer).
35

36 Hualapai monitoring programs have identified a number of issues that are negatively
37 affecting Hualapai ethnobotanical resources along the Colorado River corridor. These include the
38 disruption of riparian and nearshore plant ecology due to fluctuating river flows resulting from
39 Glen Canyon Dam operations, as well as the related increased human activity that results in
40 impacts such as trail-making and camping. Furthermore, changes in plant communities
41 themselves are not the only causes of concern. The effects of these changes on all of the various
42 forms of animal life that depend on plant communities for food, cover, nesting, and overall
43 habitat must also be considered. Understanding of the intricate web of nature is often elicited
44 through the study of Traditional Ecological Knowledge, one aspect of which acknowledges the
45 past as a time when people and animals understood one another, and are still considered
46 relatives.

1 Many of the natural resources in the canyons are considered cultural resources by the
2 Tribes. Plants have an important role in Hopi culture; they are used in ceremonies and serve as
3 clan totems, as medicines, in farming and food production, and for innumerable utilitarian
4 purposes. During Hopi ethnobotanical research in the canyons, 141 plant species were identified
5 as culturally significant. Many important plant species specifically associated with water are
6 found throughout the canyons. Beyond the direct role plants play in human life, they are also
7 recognized by the Hopi as a vital component of the ecosystem, which provides a habitat for
8 many forms of animal life
9

11 3.6.3 Special Status Plant Species

12
13 A number of special status plant species are known to occur along the Colorado River
14 from Glen Canyon Dam to Lake Mead (Table 3.6-2). None of these species are federally listed,
15 proposed for listing, or candidates for listing. Several special status species are potentially within
16 the influence of Glen Canyon Dam operations. Satintail (*Imperata brevifolia*), rice cutgrass
17 (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*) are all located within the
18 range of daily operations. The Grand Canyon evening primrose (*Camissonia specuicola* ssp.
19 *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), giant helleborine
20 (*Epipactis gigantea*), and lobed daisy (*Erigeron lobatus*), located above the level of daily flows
21 but below the 45,000-cfs stage elevation, could be affected by HFEs. Marble Canyon spurge
22 (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*) are located above the level of HFEs but
23 potentially within their influence. Sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch
24 (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*) could be affected by
25 changes in the elevation of Lake Mead.
26

27 Several special status species occurring within the Colorado River corridor are located
28 outside of dam operational effects (Makarick 2015) and therefore were dismissed from
29 consideration in the impact analysis. These include Grand Canyon cave-dwelling primrose
30 (*Primula specuicola*), Grand Canyon beavertail cactus (*Opuntia basilaris* var. *longiareolata*),
31 Kaibab agave (*Agave utahensis* ssp. *kaibabensis*), McDougall's yellowtops/Grand Canyon
32 flaveria (*Flaveria mcdougallii*), Narrow phacelia/narrow scorpion weed (*Phacelia filiformis*),
33 Desert rose/Grand Canyon rose (*Rosa stellata* ssp. *abyssa*), Canyonlands sedge/Kaibab sedge
34 (*Carex curatorum*), Ragged rock flower (*Crossosoma parviflorum*), Button brittlebush/resin
35 brittlebush (*Encelia resinifera*), Heermann's buckwheat (*Eriogonum heermannii* var. *argense*),
36 Willow glowweed/burroweed (*Lorandersonia salicina*), Ringstem (*Anulocaulis leiosolenus* var.
37 *leiosolenus*), Chaparral yucca/Our Lord's candle (*Hesperoyucca whipplei*), and Pillar false
38 gumweed (*Chrysothamnus stylosus*). Sentry milk-vetch (*Astragalus cremnophylax* var.
39 *cremnophylax*), a federally listed endangered species, is known only from the South Rim of the
40 Grand Canyon near pinyon-juniper woodlands and therefore outside of dam operational effects.
41
42

43 3.7 WILDLIFE

44
45 This section describes those animal species found along the Colorado River corridor
46 downstream of Glen Canyon Dam to Lake Mead in both the riparian zone and adjacent upland

1 **TABLE 3.6-2 Special Status Plant Species Known to Occur along the Colorado River from Glen**
 2 **Canyon Dam to Lake Mead**

Scientific Name	Common Name	State Status ^a	Federal Status ^b	Habitat/Location
<i>Camissonia specuicola</i> ssp. <i>hesperia</i>	Grand Canyon evening primrose, Kaibab suncup	None	GCNP-SC	Sandy or gravelly beaches and dry washes, often on limestone substrates (Brian 2000); located below the 45,000-cfs stage elevation, potentially affected by HFEs; Lower Granite Gorge, below Diamond Creek, Separation Canyon to Spencer Canyon (AZGFD 2013).
<i>Eriogonum viscidulum</i>	Sticky buckwheat	NCE	BLM-S, GCNP-SC	Mojave mixed scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in lake elevation.
<i>Astragalus geyeri</i>	Geyer's milkvetch	NCE	BLM-S	Creosote bush scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in lake elevation.
<i>Arctomecon californica</i>	Las Vegas bear poppy	NCE, ASR	GCNP-SC, BLM-S	Desert scrub; near RM 45, Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in lake elevation.
<i>Opuntia phaeacantha</i> var. <i>mohavensis</i>	Mohave prickly pear	ASR	GCNP-SC	River level, length of Colorado River (Brian 2000); located below the 45,000-cfs stage elevation; potentially affected by HFEs.
<i>Erigeron lobatus</i>	Lobed daisy, lobed fleabane	None	GCNP-SC	Rocky slopes, beaches, in sandy soils; located below the 45,000-cfs stage elevation; potentially affected by HFEs; RM 15–237 (Brian 2000).
<i>Epipactis gigantea</i>	Giant helleborine	ASR	GCNP-Rare	Moist soil on seepage slopes, cliff bases, along rivers, hanging gardens and seeps; located below the 45,000-cfs stage elevation; potentially affected by HFEs; from Vasey's Paradise to Grand Wash Cliffs (RM 32–277) (Brian 2000).

3

1 **TABLE 3.6-2 (Cont.)**

Scientific Name	Common Name	State Status ^a	Federal Status ^b	Habitat/Location
<i>Euphorbia aaron-rossii</i>	Marble Canyon spurge, Ross spurge	None	GCNP-Rare	Loose, sandy soil of old river bars and dunes, occasional talus slopes and rocky ledges located above the 45,000-cfs stage elevation, but potentially within influence of HFEs in Glen Canyon; also RM 3.5–53 (Brian 2000; AZGFD 2013).
<i>Imperata brevifolia</i>	Satintail	None	GCNP-Rare	Rocky canyons and wet places; located within the influence of daily operations, Clear Creek to Diamond Creek (RM 83.5–225) (Brian 2000).
<i>Leersia oryzoides</i>	Rice cutgrass	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
<i>Lycopus americanus</i>	American bugleweed	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
<i>Ptelea trifoliata</i>	Hop-tree	None	GCNRA-Rare	Located above the 45,000-cfs stage elevation, but potentially within influence of HFEs; RM –7 terrace, 1 small stand (NPS 2014b)

^a State status codes include ASR = salvage restricted, Arizona Department of Agriculture; NCE = critically endangered, Nevada.

^b Federal status codes include BLM-S = Bureau of Land Management sensitive; GCNP-Rare = Grand Canyon National Park rare; GCNP-SC = Grand Canyon National Park species of concern; GCNRA-Rare = Glen Canyon National Recreation Area rare; USFS-S = U.S. Forest Service sensitive.

2
3
4

1 vegetation communities. Along the river corridor, 90 mammals, 373 birds, 9 amphibians,
2 47 reptiles, and several thousand invertebrate species have been identified (NPS 2014b;
3 Reclamation 1995; Stevens and Waring 1986b). Many wildlife species are habitat generalists,
4 using ecosystems from both the riparian zone and upland communities to meet basic
5 requirements. Some species are habitat specialists, requiring specific vegetation composition and
6 structural components to meet their needs, and therefore may only occur within specific habitats
7 within the river corridor. There is an ecological relationship between river flow and habitat for
8 riparian and terrestrial wildlife, as illustrated in Figure 3.7-1 using birds as an example. Any
9 changes to shoreline vegetation can affect wildlife habitat. In general, many wildlife species,
10 including invertebrates, have benefited from increased riparian vegetation along the Colorado
11 River corridor (King 2005).

12
13

14 **3.7.1 Invertebrates**

15

16 The riparian and terrestrial habitats along the Colorado River corridor through Glen,
17 Marble, and Grand Canyons support a large and diverse invertebrate community. The increase in
18 post-dam riparian vegetation increased the amount of habitat and forage for riparian and
19 terrestrial invertebrates (Stevens and Waring 1986b). After construction of the dam, terrestrial
20 insect populations were more abundant and diverse in the riparian zone than in the surrounding
21 desert environment (Carothers and Aitchison 1976). Thousands of invertebrate species from over
22 260 families of arthropods are known to occur in the riparian corridor of the Grand Canyon
23 (Stevens and Waring 1986b; Reclamation 1995). These invertebrate taxa are numerically
24 dominated by terrestrial flies and adult forms of aquatic flies, herbivorous insects (especially
25 cicadas, leafhoppers, and aphids), ground-dwelling forms of spiders and scorpions, beetles, and
26 many different species of wasps, bees, and ants. These invertebrates fill a variety of ecological
27 roles and serve as pollinators, regulate populations of other invertebrates, and provide food
28 resources for many terrestrial and aquatic wildlife species. Invertebrates are discussed here based
29 on the habitats they use. Threatened, endangered, and sensitive invertebrate species that may
30 occur along the river corridor are discussed in Section 3.7.5.1.

31

32 Aquatic invertebrates downstream of Glen Canyon Dam form the food base for fish and
33 other species at higher trophic levels. Dominant aquatic invertebrates include midges, blackflies,
34 and the amphipod *Gammarus lacustris* (Section 3.5.1). Invertebrate species, particularly midges
35 and blackflies, which develop in the river and emerge to complete their life cycles among
36 riparian and terrestrial habitats, serve important ecological functions as potential prey to both
37 aquatic and terrestrial organisms. For example, light trap sampling reveals that midge emergence
38 peaks in lower Marble Canyon, but midge emergence is abundant throughout the river, both
39 close to and distant from tributaries. Adult midges contribute to the terrestrial prey base from
40 May through October (Kennedy, Muehlbauer et al. 2014).

41

42 Most invertebrate species life cycles are entirely terrestrial. Ground-dwelling
43 invertebrates, such as harvester ants (*Pogonomyrmex californicus*), occur at or just below the
44 ground surface and are known to colonize camping beaches and other sandy areas. In addition to
45 harvester ants, scorpions are also found on beaches (Carothers and Brown 1991). Before
46 construction of the dam, annual flooding would remove invertebrate species from beach areas.

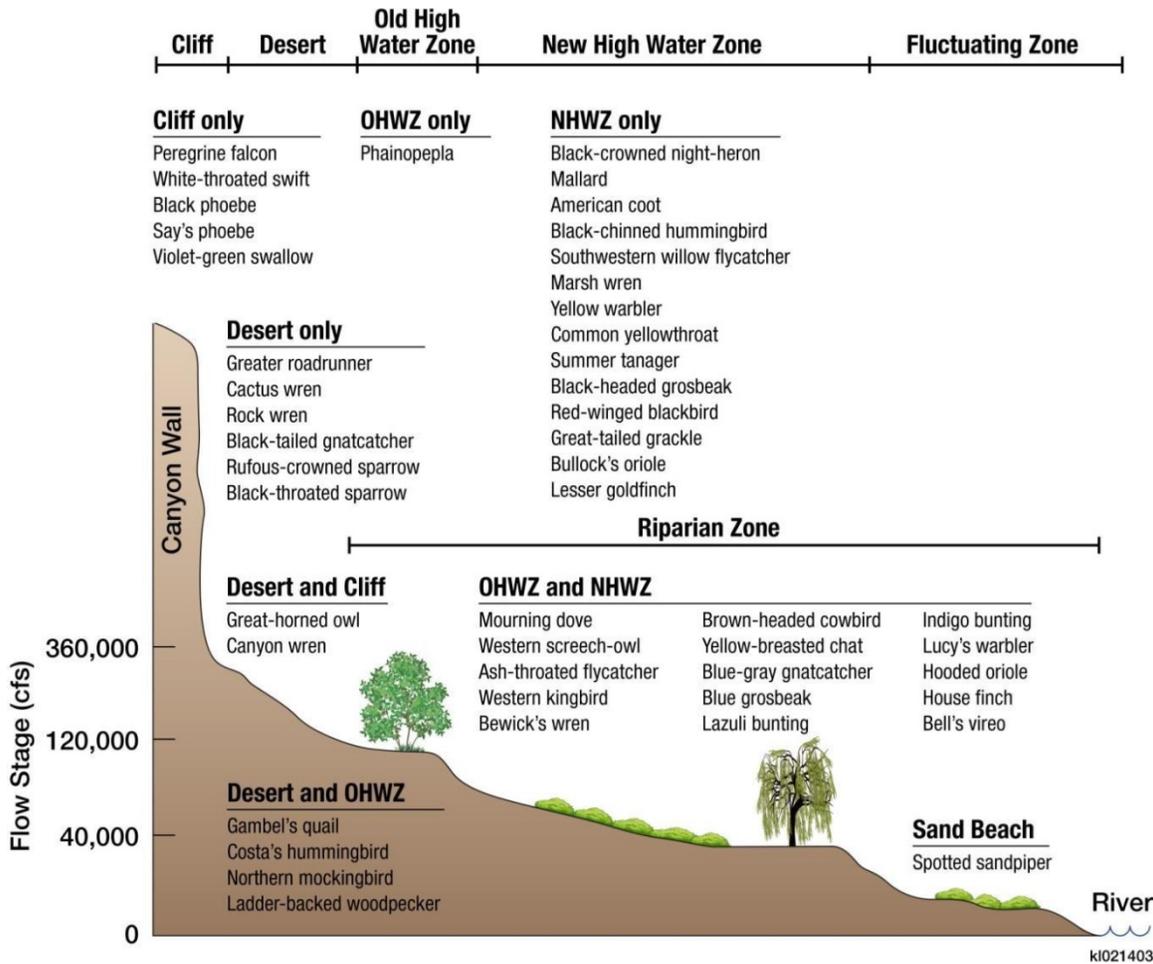


FIGURE 3.7-1 Riparian Zones Used by Nesting Birds (modified from Reclamation 1995)

Other terrestrial invertebrates that inhabit riparian vegetation and open sand communities include cicadas, leafhoppers, armored scale insects, and robber flies. Invertebrate abundance and species richness among riparian vegetation largely depend on the supporting vegetation. For example, tamarisk is the most abundant woody plant along the river corridor, but it generally supports only four or five species of insects. Coyote willow, on the other hand, supports many species of insects. Occasional high invertebrate biomass in tamarisk communities results from outbreaks of leafhoppers (Carothers and Brown 1991), which provide an important food source for other invertebrates, amphibians, reptiles, birds, and mammals. In summer, insect biomass on tamarisk is often greater than in other riparian plant communities due to high flower numbers that attract insect pollinators. Therefore, tamarisk could increase overall biomass and diversity of arthropods (van Riper et al. 2008).

The tamarisk leaf beetle was intentionally introduced in the western United States in 2001 (Nagler and Glenn 2013) to help control or eradicate tamarisk, and were first observed downstream of Glen Canyon Dam in 2009 (Section 3.6.2). The beetle, which defoliates tamarisk, has been effective in killing large numbers of tamarisk along the river corridor downstream of

1 Glen Canyon Dam. This die-off may have both negative and positive impacts for nesting bird
2 species. For example, leaf beetle defoliation of tamarisk may reduce the suitability of available
3 nest sites among tamarisk stands, but leaf beetles may also represent an important food source
4 for birds (Nagler and Glenn 2013). However, along the Dolores River in southwestern Colorado,
5 the diet of insectivorous birds consists of few tamarisk leaf beetles (2.1% by abundance and
6 3.4% by biomass) even though the beetles comprised 24% and 35.4% of arthropod abundance
7 and biomass, respectively, in the study area (Puckett and van Riper 2014).
8
9

10 **3.7.2 Amphibians and Reptiles**

11
12 Of the 47 reptile and 9 amphibian species that occur downstream of Glen Canyon Dam,
13 3 amphibian and 24 reptile species have been documented in the riparian zone of the river
14 (Carothers and Brown 1991; Kearsley et al. 2006). The highest densities and diversity of
15 amphibians and reptiles tend to occur in riparian areas nearer the river's edge due to the presence
16 of water, abundant vegetation, and invertebrate food. The amphibian species along the river
17 corridor are the canyon treefrog (*Hyla arenicolor*), red-spotted toad (*Bufo punctatus*), and
18 Woodhouse's toad (*Anaxyrus woodhousii*) (NPS 2014c). Amphibian breeding, egg deposition,
19 and larval development generally occur in backwaters or along the shallow water of aquatic and
20 riparian habitats. The northern leopard frog (*Lithobates pipiens*), identified as an AZ-SGCN
21 (AZGFD 2012), is discussed in Section 3.7.5.2.
22

23 The most common lizard species along the river corridor are the side-blotched lizard
24 (*Uta stansburiana*), western whiptail (*Aspidoscelis tigris*), desert spiny lizard (*Sceloporus*
25 *magister*), and tree lizard (*Urosaurus ornatus*) (Kearsley et al. 2006). Tree lizards use shoreline
26 habitats proportionally more than other reptile species (Kearsley et al. 2006). Within the New
27 High Water Zone, lizards feed on harvester ants and other insects in close proximity to the
28 river's edge (Carothers and Brown 1991). Warren and Schwalbe (1985) noted that lizard
29 numbers in the New High Water Zone were lowest in dense tamarisk sites. Lizards in the
30 New High Water Zone may prefer relatively open areas such as rocks and boulders, bare soil,
31 sand, or litter. Other lizard species, such as the zebra-tailed lizard (*Callisaurus draconoides*),
32 may be associated with sand substrates (Stevens 2012), the availability of which can be
33 influenced by Glen Canyon Dam flows. The high and moderate densities of lizards along the
34 shoreline and riparian habitats, respectively, are probably due to food availability on debris along
35 the shoreline and in riparian plants (Warren and Schwalbe 1985).
36

37 Over 20 snake species occur within the greater Grand Canyon area (NPS 2014c). The
38 more common species in riparian areas downstream of Glen Canyon Dam include the Grand
39 Canyon pink rattlesnake (*Crotalus viridis abyssus*), speckled rattlesnake (*Crotalus mitchellii*),
40 black-tailed rattlesnake (*Crotalus molossus*), common king snake (*Lampropeltis getula*), and
41 gopher snake (*Pituophis catenifer*) (Kearsley et al. 2006; NPS 2014c). No turtle species occur
42 below the rim of the Grand Canyon.
43
44

1 **3.7.3 Birds**
2

3 Spence et al. (2011) reported 316 bird species from the GCNRA, and Gatlin (2013)
4 reported 362 species from the Grand Canyon. NPS (2014c) reported that 373 bird species have
5 been recorded in the greater Grand Canyon region, with 250 species documented from the river
6 corridor. Riparian habitats along the river provide breeding habitat, migratory stopover sites, and
7 wintering areas for birds throughout the year (Spence 2006; Spence et al. 2011; Gatlin 2013).
8 Several of the species that breed along the river corridor are considered obligate riparian species.
9 These species include the Lucy's warbler (*Oreothlypis luciae*), Bell's vireo (*Vireo bellii*),
10 common yellowthroat (*Geothlypis trichas*), yellow warbler (*Dendroica petechia*), yellow-
11 breasted chat (*Icteria virens*), and black-chinned hummingbird (*Archilochus alexandri*). The
12 brown-headed cowbird (*Molothrus ater*), a brood parasite, is also relatively common during the
13 breeding season (Spence 2006; Spence et al. 2011; Gatlin 2013).
14

15 Birds that nest in the riparian zone along the river corridor (Figure 3.7-1) are directly and
16 indirectly affected by Colorado River flows. River flow influences the distribution and
17 composition of riparian vegetation, which affects invertebrate abundance (prey) and nest site
18 availability (Carothers and Brown 1991). Only the species that nest right at the water's edge are
19 directly influenced by fluctuating flows (Spence 2006). Important correlates with bird species
20 richness and abundance include canopy cover, size and shape of riparian patches, and canopy
21 volume and structure (Sogge et al. 1998; Spence 2006). The abundance of many bird species that
22 use riparian areas (in the lower Colorado River) was highest at intermediate tamarisk levels
23 (40–60%). In tamarisk-dominated habitats, the highest number of birds per census point occurred
24 in areas where native vegetation comprised 20–40% of the habitat. Bird numbers continue to
25 increase with increasing amounts of native vegetation up to about 60%, but did not increase in
26 numbers beyond that point (van Riper et al. 2008). Wintering birds did not show a significant
27 relationship with the amount of tamarisk in the habitat. They are not strongly associated with
28 vegetation structure but rather with habitats that provide abundant food sources of fruit and seeds
29 (van Riper et al. 2008).
30

31 Of the 30 bird species that nest in the riparian zone, at least 23 eat insects or feed insects
32 to their young. Other birds that do not nest in the riparian zone may still feed on insects within
33 this zone. Yard et al. (2004) examined the diets of six insectivorous bird species along the
34 Colorado River in GCNP. All species consumed similar quantities of caterpillars and beetles, but
35 use of other prey taxa varied. Nonnative leafhoppers (*Opsiurus stactagolus*) that inhabit tamarisk
36 made up a large portion of Lucy's warbler diets (49%); ants made up 82% of yellow-breasted
37 chat diets; and the adult stage of aquatic midges made up 45% of yellow warbler diets. Overall,
38 terrestrial insects made up 91% of bird diets compared to 9% of prey from adult insects that
39 emerged from aquatic habitats (Yard et al. 2004).
40

41 The winter terrestrial bird community is diverse, with 75 species recorded. Diversity
42 peaks in the lower portion of the Grand Canyon, particularly below RM 205 (Spence 2006). The
43 most common wintering terrestrial species are migrants, with ruby-crowned kinglet (*Regulus*
44 *calendula*) being most abundant followed by white-crowned sparrow (*Zonotrichia leucophrys*),
45 dark-eyed junco (*Junco hyemalis*), and song sparrow (*Melospiza melodia*). Most of the winter
46 terrestrial birds feed primarily on fruit and seeds (Schell 2005; van Riper et al. 2008).

1 More than 40 waterbird species inhabit the river corridor (Spence 2006;
2 Spence et al. 2011; Gatlin 2013). Waterbirds include waterfowl (e.g., ducks and geese), wading
3 birds (e.g., herons), and shorebirds (e.g., sandpipers and killdeers). Waterfowl are present mainly
4 during the winter months, while wading birds and shorebirds occur primarily as migrants or
5 during summer (Stevens, Buck et al. 1997). The winter waterfowl density in portions of the
6 Grand Canyon can be large; 31 species have been reported between Lees Ferry and Soap Creek,
7 at a density of up to 250 individuals per mile (Spence 2014b). Common waterfowl species
8 include American coot (*Fulica americana*), American widgeon (*Anas americana*), bufflehead
9 (*Bucephala albeola*), common goldeneye (*B. clangula*), common merganser (*Mergus*
10 *merganser*), gadwall (*A. strepera*), green-winged teal (*A. crecca*), lesser scaup (*Aythya affinis*),
11 mallard (*A. platyrhynchos*), ring-necked duck (*Aythya collaris*), and Canada goose (*Branta*
12 *canadensis*). Other than great blue heron (*Ardea herodias*) and spotted sandpiper (*Actitis*
13 *macularia*), which are fairly common winter and summer residents along the river, wading birds
14 and shorebirds are rare in this area (Kearsley et al. 2003; Spence 2006). Increased waterfowl
15 numbers downstream of Glen Canyon Dam developed in response to increased aquatic
16 productivity and open water, which provides wintering habitat for aquatic birds (NPS 2013b).
17 Fish-eating birds in the Grand Canyon include herons, gulls, mergansers, bald eagles (*Haliaeetus*
18 *leucocephalus*), and osprey (*Pandion haliaetus*) (Wasowicz and Yard 1993).

19
20 Several bird species appear to benefit from increased riparian habitat and river clarity and
21 productivity resulting from Glen Canyon Dam operations. For example, the increase in riparian
22 vegetation resulting from dam operations is believed to have resulted in the range expansion of
23 breeding songbirds such as Bell's vireo (Brown et al. 1983; LaRue et al. 2001). Increases in
24 abundance and species richness of aquatic bird populations have been attributed to increased
25 river clarity and productivity associated with Glen Canyon Dam operations (Spence 2006). The
26 majority of waterfowl tend to concentrate in the upper portion of the Grand Canyon due to the
27 greater primary productivity that benefits dabbling ducks and greater water clarity for diving
28 ducks. Recently, a large great blue heron rookery was established on both sides of the Colorado
29 River just below Glen Canyon Dam. In May 2013, there were 22 active nests and an estimated
30 60–80 individuals. These birds benefit from the increase availability of prey from higher trout
31 productivity of recent years and the increased water clarity. A pair of ospreys successfully nested
32 at the base of Glen Canyon Dam in 2014 (Spence 2014a,b).

33
34 Threatened, endangered, and sensitive bird species that may occur along the river
35 corridor are discussed in Section 3.7.5.3.

36 37 38 **3.7.4 Mammals**

39
40 More than 90 mammal species occur downstream of Glen Canyon Dam (NPS 2014c), of
41 which approximately 34 species occur along the river corridor (Carothers and Aitchison 1976;
42 Suttkus et al. 1978; Kearsley et al. 2006). Only three mammal species in the project area require
43 aquatic habitats: beaver (*Castor canadensis*), muskrat (*Ondatra canadensis*), and river otter
44 (*Lontra canadensis*). Muskrats are extremely rare in the Grand Canyon, but are occasionally
45 observed in the Little Colorado River (Reclamation 2011d). They construct bank dens or use
46 dens of other animals (Erb and Perry 2003). Despite occasional reports of river otters in the

1 Grand Canyon, no reliable documentation of their presence has occurred since the 1970s
2 (Kearsley et al. 2006). River otters are classified as extirpated in the Grand Canyon
3 (Reclamation 2011d) despite the apparent presence of suitable habitat (Carothers and
4 Brown 1991).

5
6 Beaver occur throughout the river corridor, from Glen Canyon Dam to the Grand Wash
7 Cliffs where riparian vegetation is well established. Beavers cut willows, cottonwoods, tamarisk,
8 and shrubs for food and can substantially affect riparian vegetation (Carothers and Brown 1991;
9 Dettman 2005). For example, Mortenson et al. (2008) hypothesized that beaver may indirectly
10 promote the invasion of nonnative tamarisk in riparian communities by preferentially feeding on
11 native competitors such as coyote willow. Beavers in the Grand Canyon excavate lodges in the
12 banks of the river, with the entrance located underwater and a tunnel leading up under the bank
13 to a living chamber. Increases in the population size and distribution of beavers in Glen Canyon
14 and the Grand Canyon have occurred since the construction of the dam. These increases are
15 likely due to the increase in riparian vegetation and relatively stable flows (Carothers and
16 Brown 1991; Kearsley et al. 2006).

17
18 Small mammal abundance and richness are greatest in the Old High Water Zone where
19 steeper slopes, rock falls, and canyon wall crevices provide greater structure for wildlife habitat
20 (NPS 2005a). Rodents (mice) are the most abundant small mammals within the riparian zone.
21 Common species include the cactus mouse (*Peromyscus eremicus*), rock pocket mouse
22 (*Chaetodipus intermedius*), and rock squirrel (*Spermophilus variegatus*) (Carothers and
23 Brown 1991). The deer mouse (*Peromyscus maniculatus*) is the only mouse species that depends
24 directly on the riparian zone (Reclamation 1995).

25
26 A least 20 species of bats are documented downstream of Glen Canyon Dam
27 (NPS 2014c). Bats in the Grand Canyon typically roost in rock crevices, caves, and trees of
28 desert uplands but forage on insects along the Colorado River and its tributaries. The most
29 common bat species along the river corridor are the western pipistrelle (*Pipistrellus hesperus*),
30 American free-tailed bat (*Tadarida brasiliensis*), pallid bat (*Antrozous pallidus*), Yuma myotis
31 (*Myotis yumanensis*), and California myotis (*Myotis californicus*). Bats are also important prey
32 for raptors such as the peregrine falcon (*Falco peregrinus*) (Carothers and Brown 1991).

33
34 A number of mammal species occur below Glen Canyon Dam. These include cougar
35 (*Puma concolor*), coyote (*Canis latrans*), bobcat (*Lynx rufus*), gray fox (*Urocyon*
36 *cinereoargenteus*), American badger (*Taxidea taxus*), raccoon (*Procyon lotor*), striped skunk
37 (*Mephitis mephitis*), western spotted skunk (*Spilogale gracilis*), American hog-nosed skunk
38 (*Conepatus leuconotus*), ringtail (*Bassariscus astutus*), and long-tailed weasel (*Mustela frenata*).
39 Omnivorous scavengers such as the ringtail and western spotted skunk have likely increased in
40 numbers due to an increase in riparian habitat and, more importantly, increases in campers and
41 river runners (Dettman 2005).

42
43 Large ungulates occurring in the Grand Canyon include the desert bighorn sheep (*Ovis*
44 *canadensis nelsoni*) and mule deer (*Odocoileus hemionus*). The Grand Canyon contains one of
45 the largest and most continuous naturally persisting populations of desert bighorn sheep in North
46 America (Bendt 1957; Guse 1974; Wilson 1976; Walters 1979; Holton 2014). GCNP has

1 prioritized the need to inventory and monitor bighorn sheep, and AZGFD lists desert bighorn
2 sheep as an AZ-SGCN (AZGFD 2012). The Navajo Nation listed this subspecies as Group 3
3 (highly likely to become extinct throughout its range on the Navajo Nation).
4

5 Bighorn sheep in the Grand Canyon occupy an environment that is unique relative to
6 other desert bighorn sheep ranges. Most desert bighorn sheep populations occupy arid mountain
7 ranges with limited (largely point) water sources and are near enough to other populations for
8 effective dispersal and interbreeding. By contrast, bighorn sheep in the Grand Canyon live in a
9 comparatively isolated, very deep canyon with abundant free water along the bottom
10 (Holton 2014). Bighorn sheep routinely use free water and do not often move farther than 1.2 to
11 5 mi from water sources (Turner et al. 2004; Epps et al. 2007; Longshore et al. 2009). Bighorn
12 sheep in the Grand Canyon routinely come to the river to drink and forage during the summer
13 months (Carothers and Brown 1991). Holton (2014) reported that most ewes in the Grand
14 Canyon remained near the river year-round, rarely moving more than a few hundred yards above
15 the river.
16

17 Human-related barriers that restrict or eliminate dispersal to and colonization of suitable
18 ranges affect the viability of desert bighorn sheep (Bleich et al. 1990; Epps et al. 2007). Swift
19 wide rivers are noted to effectively delimit bighorn ranges (Graham 1980; Wilson et al. 1980;
20 Smith and Flinders 1991). The Colorado River likely serves as a natural impediment for
21 interbreeding and connectivity between populations (Holton 2014). Bighorn in the Grand
22 Canyon have not been seen crossing the Colorado River since construction of Glen Canyon
23 Dam. However, some individual bighorns have been more genetically similar to bighorn herds
24 from the opposite side of the river, suggesting that recent ancestors crossed the river
25 (Holton 2014). Prior to construction of the dam, seasonally low water along the Colorado River
26 likely allowed movement across the river. Early naturalists at the Grand Canyon speculated that
27 a bighorn, before the dam was built, could perhaps boulder-hop across the Colorado River
28 without ever touching water. Consistent high flows of the Colorado River have likely created a
29 formidable barrier, eliminating seasonal movements of bighorn sheep across the river and
30 potentially restructuring the population in GCNP over the last 50 years (Holton 2014).
31

32 Studies also indicate that bighorn sheep populations may be limited through resource
33 competition with feral burros (*Equus asinus*). In areas of sympatry, the shared foods consumed
34 by burros may be twice the amount consumed by bighorn sheep. The burro is apparently a
35 superior competitor compared to bighorn sheep. Following competitive equilibrium, the bighorn
36 sheep would be relegated mainly to surviving in the most rugged habitats that could not be
37 efficiently exploited by burros (Seegmiller and Ohmart 1981). Carothers (1977) reported that
38 burros had affected natural communities in the three distinct plant associations (pinyon-juniper
39 woodlands, high desert blackbrush community, and Mojave Desert vegetation type) that occur
40 below the rims of the Grand Canyon. The most widespread impact of burro-related change was
41 the reduction and elimination of palatable grasses and their replacement by unpalatable shrubs.
42 Burro activity also increased soil compaction and accelerated soil loss (Carothers 1977). Burro
43 control has been conducted in the Grand Canyon in an attempt to prevent them from denuding
44 plateaus of grass and other forage plants consumed by native big game species such as bighorn
45 sheep (Wright 1992). Low numbers of burros remain in the western portion of GCNP, and are
46 removed whenever possible (NPS 2005a).

1 Mule deer occur in relatively low densities along the river corridor as compared to the
2 densities on North and South Rims of the Grand Canyon. Small herds of deer are commonly seen
3 along the river in the upper reaches of the canyon, from Buck Farm to Kwagunt Canyons.
4 Anecdotally, mule deer have been observed swimming across the river (NPS 2014c).

7 **3.7.4.1 Tribal Perspectives on Wildlife Species**

8
9 The following paragraph was provided by the Pueblo of Zuni for inclusion in this DEIS:

10
11 Riparian and terrestrial wildlife play an important role in Tribal culture and religion. The
12 loss of animals or plants may have a negative cultural impact on the life of the Tribes in the
13 region. In the Zuni belief system, as Winston Kallestewa explained (in Dongoske and Seowtewa
14 2013), “All animals are our ancestors that have come back to life in a different form—that is why
15 all living beings, even the smallest insect, are important to the Zuni people.” Dickie Shack
16 explained (in Dongoske and Seowtewa 2013) that common animals such as lizards play a role in
17 Ant Medicine Society prayers, prayers so ancient that they are spoken in an archaic language,
18 learned when the Zunis were on their migration. In addition, animals, plants, and insects play a
19 fundamental role in Zuni clan identity and collectively as Zuni people. All animals came out of
20 the underworld with the Zunis. They are all important because they have a purpose explained in
21 Zuni religion and cannot be killed indiscriminately. Wildlife are the spiritual beings of the
22 ancestors for the Zuni people and are mentioned in prayers and songs (Dongoske and Seowtewa
23 2013). Birds are incorporated into nearly every aspect of Zuni life (Ladd 1963). Because they are
24 viewed as messengers from the ancestral celestial beings, their appearance is closely watched.
25 Consequently, Zunis are generally excellent ornithologists. In discussing the cultural importance
26 of birds with Zuni cultural advisors, one becomes quickly amazed at the accuracy and
27 consistency with which they distinguish closely related species, and are able to relate precisely
28 the season when each species is present. Throughout the migration of the Zuni people to find the
29 Middle Place, they were also helped by birds: a raven took the bitterness away from the corn the
30 Zunis had harvested and made it palatable; an owl helped them by making the corn which they
31 had harvested soft enough to eat. Although birds are probably the most important animals to
32 Zuni, they are far from the only animals that Zunis view as religiously or culturally important.
33 All animals have their place of reverence in Zuni cosmology (Tyler 1964). As mentioned above,
34 even if Zunis did not need to collect any of these animals, their appearance is emblematic and
35 auspicious of natural events, or human’s response to them. During the Zunis’ effort to emerge
36 and reach the upper world, they were helped by small creatures: a locust who, like the three birds
37 before him, attempted to reach the upper world, and a spider, and a water strider, who eventually
38 direct the Zuni people to Halona-itiwana, the Middle Place. Zunis have a special relationship
39 with water creatures, and this stems from events during their search for the Middle Place.

40
41 For the Hopi, snakes and other reptiles play valued cultural roles in history and
42 ceremonial activities. The presence of the Snake and Lizard clans at Hopi testifies to their
43 ongoing importance. The Snake ceremony has its origins in the canyons and is associated with
44 the journeys of Tiyo down the Colorado River (Eggan 1971). Birds are a valuable cultural
45 resource to the Hopi people. Feathers of a great many species are used in ceremonial and ritual
46 contexts. Of particular importance are eagles, whose nests are viewed as shrines and used as

1 receptacles for prayer offerings. Maintaining healthy populations of birds is part of the overall
2 balance of the world.

3
4 Bighorn sheep are revered and culturally significant for nearly every Tribe with historical
5 ties to the Grand Canyon. Historically they were important for food, hides, and materials used in
6 making tools and implements. The Havasupai have a close cultural affinity with the bighorn
7 sheep and do not hunt them. The ram horns feature in the tribal seal and tribal identity. They
8 furthermore figure prominently in cosmology and star lore, and are considered relatives that,
9 when the need arises, give up their life to provide sustenance.

12 **3.7.5 Special Status Wildlife Species**

13
14 Threatened, endangered, and sensitive wildlife species include species that may occur
15 along the Colorado River corridor between Glen Canyon Dam and Lake Mead and that are any
16 of the following:

- 17
18 • Listed or proposed for listing as threatened or endangered plant and wildlife
19 species under the Endangered Species Act of 1973, as amended (ESA)
20 (including experimental, nonessential populations) and designated and
21 proposed designated critical habitat;
- 22
23 • Candidates for listing as threatened or endangered species under the ESA;
- 24
25 • State of Arizona Species of Greatest Conservation Need (AZ-SGCN); or
- 26
27 • Bald or golden eagles protected by the Bald and Golden Eagle Protection Act
28 of 1940 (BGEPA).

29
30 Eleven threatened, endangered, and sensitive wildlife species may occur along the
31 Colorado River corridor between Glen Canyon Dam and Lake Mead. These species and their
32 critical habitats are discussed below.

35 **3.7.5.1 Invertebrates**

36
37 The Kanab ambersnail (*Oxyloma haydeni kanabensis*) (Table 3.7-1) is the only
38 threatened, endangered, or sensitive invertebrate species that occurs along the Colorado River in
39 the Grand Canyon. The Kanab ambersnail was listed as an endangered species under the ESA on
40 April 17, 1992 (FWS 1992). However, recent evidence from anatomical and molecular genetics
41 studies indicate that this is a geographically widespread taxon whose listing under the ESA may
42 have been incorrect (Littlefield 2007). In a study of *Oxyloma* specimens collected from
43 12 locations throughout the western United States, including Kanab ambersnail from the Grand
44 Canyon, morphometric and genetic results indicated that the Kanab ambersnail can be regarded
45 as a member of the same species as the other *Oxyloma* populations analyzed (Culver et al. 2013).

1 **TABLE 3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife Species along the Colorado River Corridor**
 2 **between Glen Canyon Dam and Lake Mead**

Common Name	Scientific Name	Status ^a	Habitat and Distribution Downstream from Glen Canyon Dam
<i>Invertebrates</i>			
Kanab ambersnail	<i>Oxyloma haydeni kanabensis</i>	ESA-E; AZ-SGCN	Known at only two locations within the Grand Canyon: Vasey’s Paradise and Elves Chasm. These spring-fed sites occur along the river corridor. Lives in association with watercress (<i>Nasturtium</i>), monkeyflower (<i>Mimulus</i> spp.), cattails (<i>Typha</i> spp.), sedges (<i>Carex</i> spp.), and rushes (<i>Juncus</i> spp.).
<i>Amphibians and Reptiles</i>			
Northern leopard frog	<i>Lithobates pipiens</i>	AZ-SGCN	Presumably extirpated from Glen and Grand Canyons.
<i>Birds</i>			
American peregrine falcon	<i>Falco peregrinus</i>	AZ-SGCN	Common along the river corridor in summer, with about 100 pairs nesting along the cliffs of the inner Grand Canyon. Most migrate south in winter. In the Grand Canyon, common prey items in summer include riparian bird species, many of which feed on invertebrates that emerge out of the Colorado River and the adjacent riparian zone. In winter, a common prey item is waterfowl.
Bald eagle	<i>Haliaeetus leucocephalus</i>	AZ-SGCN; BGEPA	Wintering populations are known to occur in Marble Canyon and the upper half of the Grand Canyon. Wintering individuals are known to occur at tributary confluences.
California condor	<i>Gymnogyps californianus</i>	ESA-XN; AZ-SGCN	An experimental nonessential population occurs within the Grand Canyon. Releases of condors near the Grand Canyon began in 1996. The beaches of the Colorado River through the Grand Canyon are frequently used by condors for drinking, bathing, preening, , and feeding on fish carcasses. An increase in interactions between condors and recreationists within the Grand Canyon has been observed.
Golden eagle	<i>Aquila chrysaetos</i>	AZ-SGCN; BGEPA	Rare to uncommon permanent resident and a rare fall migrant. Prefer rugged terrain of cliffs and mesas, and nests on cliff ledges. Migrants use sheer cliffs of the Glen Canyon area to hunt. Feeds on mammals, birds, and reptiles.

3-127

TABLE 3.7-1 (Cont.)

Common Name	Scientific Name	Status ^a	Habitat and Distribution Downstream of Glen Canyon Dam
Birds (Cont.)			
Osprey	<i>Pandion haliaetus</i>	AZ-SGCN	Large numbers use the Colorado River corridor during fall migration, usually August–September with a peak in late August. An osprey pair successfully nested near the base of Glen Canyon Dam in 2014.
Southwestern willow flycatcher	<i>Empidonax traillii extimus</i>	ESA-E; AZ-SGCN	Observed throughout the Grand Canyon in riparian habitats along the river corridor, including those dominated by invasive tamarisk. In recent years, flycatchers have consistently nested along the river corridor as new riparian habitat, primarily tamarisk, has developed in response to flow regimes. Resident birds have been documented in a small stretch of Marble Canyon and the lower Canyon near the inflow of Lake Mead.
Western yellow-billed cuckoo	<i>Coccyzus americanus occidentalis</i>	ESA-T; AZ-SGCN	Known to occur at a number of sites in the Grand Canyon near the Lake Mead National Recreation Area delta. The riparian community at these sites is primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in these sites. However, surveys for this species at these sites resulted in no detections in 2007.
Yuma clapper rail	<i>Rallus longirostris yumanensis</i>	ESA-E; AZ-SGCN	Casual summer visitor to marshy mainstem riparian habitats below Separation Canyon (e.g., in the Spencer Canyon and Burnt Springs areas near RM 246 and RM 260, respectively). Sight records in the study area are quite distant from its breeding range on the lower Colorado River.
Mammals			
Spotted bat	<i>Euderma maculatum</i>	AZ-SGCN	Rarely encountered throughout the State of Arizona, but may occur in areas near cliffs and water sources. Roosts primarily in crevices and cracks in cliff faces. Bats have been known to roost in cliff faces along the river corridor. Foraging may occur in riparian areas in the action area.

^a ESA = Endangered Species Act; E = listed as endangered; T = listed as threatened; XN = experimental nonessential population; AZ-SGCN = Arizona Species of Greatest Conservation Need; BGEPA = Bald and Golden Eagle Protection Act.

Sources: AZGFD (2002d–h, 2003b, 2010, 2012); FWS (1967; 1992; 1995a,b; 1996; 2014b); Gatlin (2013); NatureServe (2014); NPS (2015a); Reclamation (1995, 2007d).

1 However, until this taxonomic change occurs, the Kanab ambersnail remains a listed species
2 (FWS 2011b). No critical habitat is designated for this species.
3

4 Globally, the Kanab ambersnail is only found in three locations. Two of these are within
5 the Grand Canyon: the riparian vegetation at Vasey's Paradise and Elves Chasm. Vasey's
6 Paradise is at RM 31.5 and Upper Elves Chasm is at RM 116.6. The latter population was
7 created from snails translocated from Vasey's Paradise (Sorensen and Nelson 2000; FWS 2008).
8 The locations of these sites within the Grand Canyon are shown in Figure 3.7-2. The third
9 location for the Kanab ambersnail is Three Lakes near Kanab, Utah (FWS 1995a).
10

11 The Kanab ambersnail lives in association with watercress (*Nasturtium officinale*),
12 cardinal monkeyflower (*Mimulus cardinalis*), cattails (*Typha*), sedges (*Carex*), and rushes
13 (*Juncus*). Populations within the Grand Canyon occur in areas with water sources originating
14 from limestone or sandstone geologic strata (Spamer and Bogan 1993; FWS 1995a). The
15 increase in cover, reduction in beach-scouring flows, and introduction of the nonnative
16 watercress led to a >40% increase in suitable Kanab ambersnail habitat area at Vasey's Paradise
17 compared to pre-dam conditions (Stevens, Protiva et al. 1997).
18

19 Kanab ambersnails live 12 to 15 months and are capable of self-fertilization. Mating and
20 reproduction occur from May to August. Subadults dominate the overwinter population. Snails
21 enter dormancy in October–November and become active in March–April. Overwinter mortality
22 ranges between 25 and 80% (Stevens, Protiva et al. 1997; IKAMT 1998). During mild winters,
23 they can continue their life cycle without dormancy or may go in and out of dormancy several
24 times throughout the winter (Sorensen and Nelson 2002).
25

26 Based on annual survey data, live counts of Kanab ambersnails at Vasey's Paradise
27 declined in 2011 from previous years, although the ambersnail habitat at Vasey's Paradise was in
28 overall good condition in 2011. At Elves Chasm, live counts of ambersnails remained higher in
29 2011 than previous years, and habitat at this location was in good condition in 2011
30 (Sorensen 2012). The population at Vasey's Paradise generally occurs at elevations above
31 33,000 cfs flows. However, as much as 7.3% of the Vasey's Paradise population occurs below
32 the elevation of 33,000 cfs flow and as much as 16.4% of the population occurs below the
33 elevation of 45,000 cfs flow. The Elves Chasm population is located above the elevation of
34 45,000 cfs flow (Reclamation 2011d).
35
36

37 **3.7.5.2 Amphibians and Reptiles**

38

39 The northern leopard frog (*Lithobates pipiens*) is the only threatened, endangered, or
40 sensitive amphibian or reptile species that occurred recently along the Colorado River
41 downstream from Glen Canyon Dam (Table 3.7-1). Although the northern leopard frog is not
42 listed under the ESA, it is identified as an AZ-SGCN (AZGFD 2012). In 2006, the FWS was
43 petitioned to list the frog in 18 western states but, in 2011, the agency found that listing of this
44 species was not warranted (76 FR 61896). The northern leopard frog occurs in northeastern and
45 north-central Arizona in and near permanent water with rooted aquatic vegetation
46 (AZGFD 2002g). Populations of the northern leopard frog along the lower Colorado River have

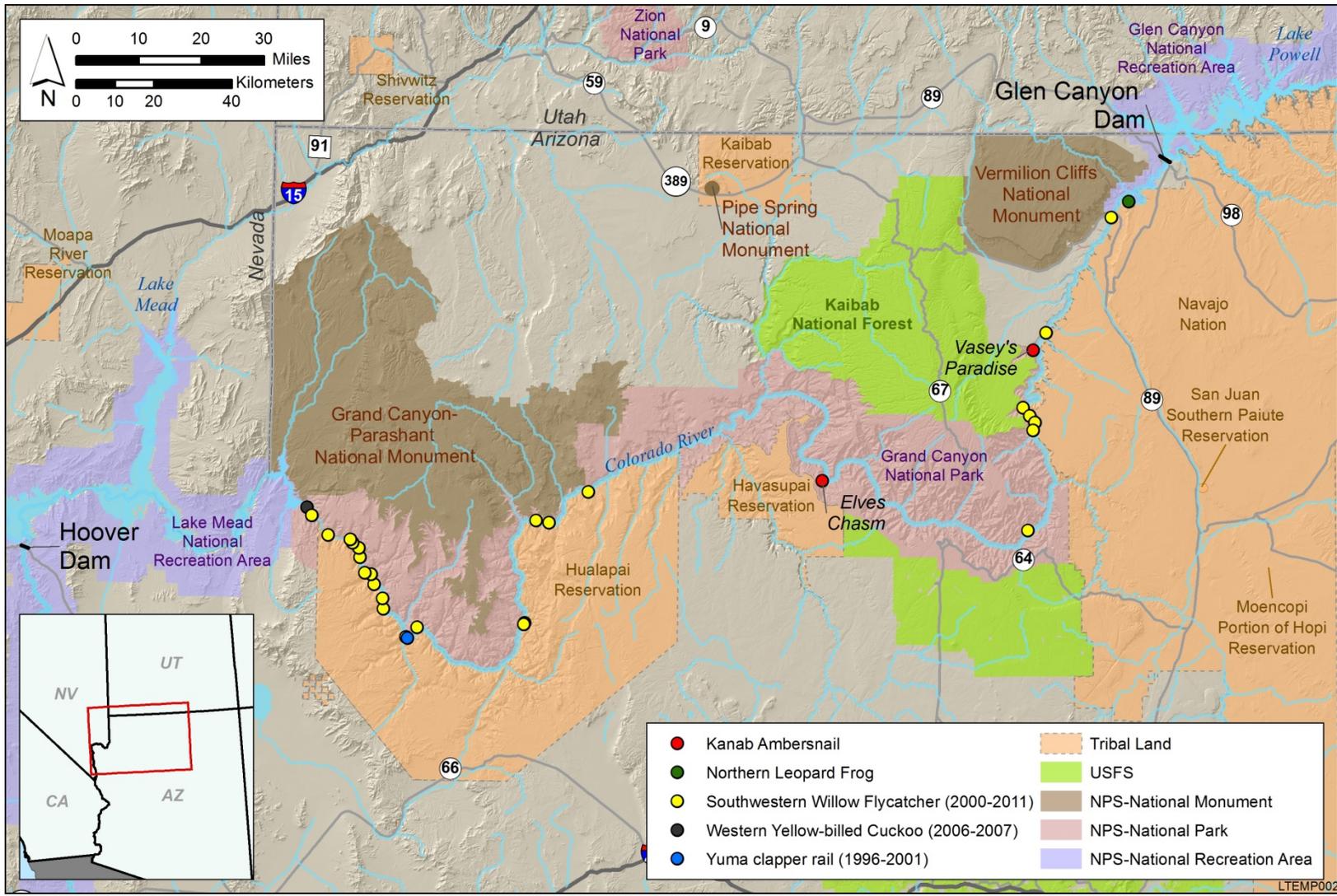


FIGURE 3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor
(Sources: Drost et al. 2011; FWS 2011b; Johnson et al. 2008; NPS 2013e; Stroud-Settles 2012)

3-130

1
2
3

1 declined since the construction of Glen Canyon Dam. Leopard frogs have disappeared from 70%
2 of the known sites above and below Glen Canyon Dam, and there appear to be declines among
3 some of the remaining populations (Drost 2005; Drost et al. 2011). Populations above the dam
4 are declining for a number of reasons, particularly due to the introduction of nonnative fishes and
5 changes in habitat. In years when the reservoir is full, nonnative fishes can move into tributary
6 canyons occupied by the northern leopard frog in Glen Canyon.
7

8 The leopard frog breeds from mid-March to early June. Females lay up to 5,000 eggs.
9 The tadpoles hatch in about a week and metamorphosis occurs in about three months
10 (AZGFD 2002g). Tadpoles consume algae, plant tissue, organic debris, and small invertebrates;
11 while adults prey on invertebrates and rarely small vertebrates (AZGFD 2002g).
12

13 The only known population of the northern leopard frog below the dam was located in
14 Glen Canyon in a series of off-channel pools at RM 8.8 (Figure 3.7-2). Marsh habitat at this
15 location was fed by a natural spring. Dominant vegetation included water sedge (*Carex aquatilis*)
16 and southern cattail (*Typha domingensis*). Inundation at this site occurs at approximately
17 21,000 cfs. Following the experimental flood of 1996, the number of frogs at this location was
18 estimated at a high of 177 individuals (Reclamation 2008c). Since that time, the population size
19 has decreased. In 2004, only two adults were found (Drost 2005), and the northern leopard frog
20 has not been observed since (Drost et al. 2011). It is assumed that the northern leopard frog
21 population at this site has been lost due to loss of pond and marsh habitat. The species is
22 presumed extirpated in Glen and Grand Canyons (downstream from Lees Ferry).
23

24 No listed or sensitive reptile species occur in the river corridor downstream of Glen
25 Canyon Dam.
26

27 **3.7.5.3 Birds**

28
29
30 Threatened, endangered, and sensitive bird species that may occur in the aquatic and
31 riparian habitats along the Colorado River downstream of Glen Canyon Dam include the
32 American peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), California
33 condor (*Gymnogyps californianus*), golden eagle (*Aquila chrysaetos*), osprey
34 (*Pandion haliaetus*), southwestern willow flycatcher, western yellow-billed cuckoo
35 (*Coccyzus americanus occidentalis*) and Yuma clapper rail (*Rallus longirostris yumanensis*). The
36 distribution, habitat, and population trends of these species along the river corridor downstream
37 of Glen Canyon Dam are described below and summarized in Table 3.7-1. The Mexican spotted
38 owl (*Strix occidentalis lucida*; federally listed as threatened) is known to occur in the Grand
39 Canyon but typically inhabits higher elevation forested side canyons above the river corridor
40 (Bowden 2008).
41

42 **American Peregrine Falcon**

43
44
45 The American peregrine falcon was listed as endangered under the ESA on June 2, 1970.
46 Following restrictions on organochlorine pesticides in the United States and Canada, and

1 implementation of various management actions, including the release of approximately
2 6,000 captive-reared falcons, recovery goals were substantially exceeded in some areas, and on
3 August 25, 1999, the falcon was removed from the federal list of threatened and endangered
4 species (FWS 1999). This species is identified as an AZ-SGCN (AZGFD 2012).
5

6 Although peregrine falcons are uncommon year-round residents in the project area, the
7 population has gradually increased since the 1970s (Carothers and Brown 1991). Peregrine
8 falcons, which generally mate for life, nest regularly in Marble Canyon between Lees Ferry and
9 the Little Colorado River confluence where cliffs >150 ft are abundant (Schell 2005). About
10 100 pairs of peregrine falcons nest along the cliffs of the inner Grand Canyon (NPS 2014c). In
11 Arizona, peregrine falcons return to breeding areas from mid-February to mid-March, with egg
12 laying occurring anytime from mid-March through mid-May. Fledging occurs from May to
13 August (AZGFD 2002h). In the Grand Canyon, common prey items in summer include the
14 white-throated swift (*Aeronautes saxatalis*), swallows, other song birds, and bats (Carothers and
15 Brown 1991; Stevens et al. 2009). In winter, most adult falcons migrate south. For those falcons
16 that remain for the winter, waterfowl is a common prey item (Schell 2005).
17
18

19 **Bald Eagle**

20
21 The bald eagle was originally listed as an endangered species under the ESA in 1967 and
22 down-listed to threatened status in 1995. It was removed from the federal list of threatened and
23 endangered species on July 9, 2007 (FWS 2007b). It is still federally protected under the Bald
24 and Golden Eagle Protection Act. This species is identified as an AZ-SGCN (AZGFD 2012).
25

26 A wintering concentration of bald eagles was first observed in the Grand Canyon in the
27 early 1980s, and numbers had increased by 1985 (Brown et al. 1989; Brown and Stevens 1997).
28 Territorial behavior, but no breeding activity, has been observed in the canyon. This wintering
29 population was monitored through the 1980s and 1990s in Marble Canyon and the upper half of
30 the Grand Canyon. The number of Grand Canyon bald eagles during the winter (late February
31 and early March) ranged from 13 to 24 birds between Glen Canyon Dam and the Little Colorado
32 River confluence from 1993 to 1995 (Sogge et al. 1995). A concentration of wintering bald
33 eagles often occurred in late February at the mouth of Nankoweap Creek, where large numbers
34 of rainbow trout congregated to spawn (Gloss et al. 2005). However, a flash flood destroyed the
35 trout spawning habitat and separated the tributary mouth from the Colorado River, so the eagles
36 no longer congregate at that tributary. Small numbers of wintering eagles (1–3) have also been
37 noted around Bright Angel Creek, presumably also preying on nonnative fish. Since 1996, the
38 number of wintering bald eagle observations in the Grand Canyon has declined.
39

40 **California Condor**

41
42
43 The California condor was listed as an endangered species under the ESA on March 11,
44 1967 (FWS 1967), and is identified as an AZ-SGCN (AZGFD 2012). By the 1930s, it was
45 considered extirpated from the State of Arizona (NPS 2014c). A captive rearing program was
46 initiated in 1983 to assist in recovery efforts. On October 16, 1996, it was announced that a

1 nonessential population of condors would be established in northern Arizona (FWS 1996). On
2 October 29, 1996, six condors were released at Vermillion Cliffs near Glen Canyon. Since that
3 time, there have been additional releases and the experimental population that inhabits the Grand
4 Canyon as of September 2014 included 76 individuals (NPS 2014c). California condors are
5 opportunistic scavengers, preferring carcasses of large mammals, but they will also feed on
6 rodents and fish. Depending on weather conditions and the hunger of the bird, a California
7 condor may spend most of its time perched at a roost. Roosting provides an opportunity for
8 preening, other maintenance activities, and rest, and possibly facilitates certain social functions
9 (FWS 1996). Nest sites often occur in caves and rock crevices (NPS 2014c).

10
11 California condors often use traditional roosting sites near important foraging grounds.
12 Cliffs and tall conifers, including dead snags, are generally used as roost sites in nesting areas.
13 Although most roost sites are near nesting or foraging areas, scattered roost sites are located
14 throughout their range. California condors frequent beaches of the Colorado River through the
15 Grand Canyon (Reclamation 2011b). Activities include drinking, bathing, preening, and feeding
16 on fish carcasses. Condor monitors noted an increase in interaction between rafters and condors
17 in 2002 as rafting parties sought out unused beaches for lunch stops, exploration, and close
18 observance of condors. There have been several instances of immature condors approaching
19 campsites.

20 21 22 **Golden Eagle**

23
24 The golden eagle is federally protected under the Bald and Golden Eagle Protection Act,
25 and is identified as an AZ-SGCN (AZGFD 2012). It is a rare to uncommon permanent resident
26 and a rare fall migrant throughout the region (Gatlin 2013). Preferred habitat is rugged terrain of
27 cliffs and mesas, with nests built of large sticks on cliff ledges (NPS 2015a). Nesting has been
28 documented from several areas of GCNRA. From November through March, the golden eagle
29 can be observed on the high cliffs around Lake Powell (NPS 2015a). Winter aerial surveys have
30 documented three to 25 individuals per survey. Since 2002, there has been a steady decline in
31 golden eagle numbers within the Glen Canyon region (Spence et al. 2011). The golden eagle
32 generally feeds on small mammals (e.g., rabbits and ground squirrels), but it also preys on large
33 insects, birds, reptiles, and carrion, and can feed on mammals up to the size of small deer
34 (NatureServe 2014; NPS 2015a).

35 36 37 **Osprey**

38
39 Although the osprey is not listed under the ESA, it is identified as an AZ-SGCN
40 (AZGFD 2012). Reclamation (1995) stated that the osprey was a rare fall, spring, or accidental
41 transient in the Grand Canyon. However, large numbers of ospreys now use the Colorado River
42 corridor during fall migration, usually August–September with a peak in late August. There can
43 be 10 to 12 individuals between Glen Canyon Dam and Lees Ferry on any given day during that
44 period. An osprey pair nested near the base of Glen Canyon Dam in 2014 and 2015. In 2014,
45 three eggs were laid and, although all three hatched, only one hatchling survived to fledge
46 (Spence 2014a). One hatchling also fledged in 2015. Because nest sites are typically used for

1 many years (AZGFD 2002f), this nest may be used in the future. The osprey feeds almost
2 exclusively on fish, although it will also prey on snakes, frogs, shorebirds, and waterfowl
3 (AZGFD 2002f).
4
5

6 **Southwestern Willow Flycatcher**

7

8 The southwestern willow flycatcher (flycatcher) is a neotropical migrant that nests in
9 dense riparian habitats in the six southwestern states of California, Nevada, Utah, Colorado,
10 Arizona, and New Mexico. The Pacific lowlands of Costa Rica appear to be a key winter
11 location for the southwestern willow flycatcher, although other countries in Central America
12 may also be important (Paxton et al. 2011). This subspecies of the willow flycatcher was listed as
13 endangered under the ESA in 1995 (FWS 1995b). It is identified as an AZ-SGCN
14 (AZGFD 2012). Historically, the range of the flycatcher in Arizona included portions of all
15 major watersheds (FWS 2002b); however, these watersheds have changed in many cases. As a
16 result, most of the areas where flycatchers were locally abundant now support few or no
17 individuals (FWS 2002b). Habitat and population numbers of southwestern willow flycatchers
18 have declined in recent decades due to several factors including loss, degradation, and
19 fragmentation of riparian habitat; invasion by nonnative plants; brood parasitism by brown-
20 headed cowbirds; and loss of wintering habitat (Stroud-Settles et al. 2013). Under the species
21 recovery plan (FWS 2002b), the Colorado River downstream of Glen Canyon Dam falls within
22 the Middle Colorado Management Unit delineated within the Lower Colorado Recovery Unit.
23 Critical habitat for the southwestern willow flycatcher has not been designated by the FWS
24 between Glen Canyon Dam and Lake Mead (FWS 2005, 2013b).
25

26 The southwestern willow flycatcher eats insects and needs riparian habitats to complete
27 its life cycle. It breeds and forages in dense, multi-storied riparian vegetation near saturated soils,
28 slow-moving water, or surface water (Sogge et al. 1995). The southwestern willow flycatcher
29 breeds across the lower southwest from May through August (Reclamation 2007d). The
30 southwestern willow flycatcher arrives on the breeding grounds throughout May and early June,
31 eggs are generally laid beginning in May, and fledging occurs between June and August
32 (Sogge et al. 1997, 2010). Occupied sites most often have a patchy interior of dense vegetation
33 or dense patches of vegetation intermingled with openings. Most often, this dense vegetation
34 occurs within the first 3 to 4 m above the ground (FWS 2002b). The structures of occupied
35 patches vary, with a scattering of small openings, shorter vegetation, and open water. Occupied
36 patches can be as small as two acres and as large as several hundred acres, but are typically
37 >10 m wide (Reclamation 2007d).
38

39 The southwestern willow flycatcher historically nested in native plants such as willows,
40 buttonbush, boxelder, and seepwillow (Stroud-Settles et al. 2013). It also nests in patches
41 dominated by exotic plant species such as tamarisk and Russian olive (Sogge et al. 1997;
42 Stroud-Settles et al. 2013). The Grand Canyon does not provide extensive stands of dense
43 riparian habitat suited for breeding willow flycatchers. The majority of habitat patches in the
44 Grand Canyon lack a consistent, dependable source of water for maintaining moist/saturated soil
45 conditions and/or slow-moving or standing surface water (Stroud-Settles et al. 2013). As a result,
46 the majority of flycatcher habitats in the Grand Canyon are marginal and, unless current

1 hydrological conditions change, these patches will likely continue to decline. Furthermore, the
2 recent arrival of the tamarisk leaf beetle has transformed and will continue to transform the
3 patches of dense tamarisk into unpredictable, diminished patches (Stroud-Settles et al. 2013).
4

5 Surveys for the flycatcher have occurred in the Grand Canyon, mainly along the main
6 stem of the river corridor, since 1982. The number of nesting flycatcher detections have declined
7 since the 1980s, and nesting flycatchers have not been confirmed in the Grand Canyon since
8 2007, although formal nest searches have not been conducted above Diamond Creek since 2004
9 (Stroud-Settles et al. 2013). There is little information on the number of flycatchers present along
10 the river before the construction of Glen Canyon Dam. However, what data are available suggest
11 that historically flycatchers were not common breeders along the Colorado River in the Grand
12 Canyon (Sogge et al. 1997; Stroud-Settles et al. 2013). Studies conducted along the river from
13 1982 to 1991 and from 1992 to 2001 detected 14–15 breeding pairs per decade of surveys
14 between Lees Ferry and Phantom Ranch (Stroud-Settles et al. 2013).
15

16 In the Grand Canyon, the river stretch from Lees Ferry to Phantom Ranch has been
17 surveyed most consistently since 1982 and best represents the potential trend of the flycatcher in
18 Grand Canyon (Stroud-Settles et al. 2013). There has been a noticeable decrease in the detection
19 of breeding pairs since the 1990s along this stretch of river. The river stretch from Phantom
20 Ranch to Diamond Creek has infrequent habitat patches. Surveys did not occur along this stretch
21 until the 1990s and have produced minimal detections. The previous studies along the Diamond
22 Creek–Pearce Ferry river stretch have varied considerably. A 5-year boost in detections along
23 this stretch of river that occurred from 1997 to 2001 is likely due to favorable water levels of
24 Lake Mead in combination with increased survey effort (Stroud-Settles et al. 2013). The river
25 corridor continues to provide essential habitat for migrating southwestern willow flycatcher
26 (Stroud-Settles et al. 2013).
27
28

29 **Western Yellow-billed Cuckoo**

30

31 The western yellow-billed cuckoo distinct population segment was designated as a
32 threatened species under the ESA on October 3, 2014 (FWS 2014b). This species is also
33 identified as an AZ-SGCN (AZGFD 2012). Proposed designated critical habitat does not occur
34 between Glen Canyon Dam and Lake Mead. A 24-km continuous segment of the Colorado River
35 between the upstream end of Lake Mead and the Kingsmen Wash area in Mohave County is the
36 closest unit of proposed designated critical habitat (FWS 2014a).
37

38 The western yellow-billed cuckoo is a neotropical migrant bird that breeds and summers
39 in northern Mexico and the western United States. Cuckoos were once considered abundant
40 throughout the riparian floodplain along the lower Colorado River (Table 3.7-1). However,
41 cuckoo populations have suffered severe range contractions during the last 80 years; currently
42 western populations breed in localized areas of California, Arizona, New Mexico, western Texas,
43 and northern Mexico, with irregular breeding in Utah and western Colorado
44 (Johnson et al. 2008). Factors that have contributed to population declines of the western yellow-
45 billed cuckoo include habitat loss, fragmentation, and degradation of native riparian breeding

1 habitat; possible loss of wintering habitat; limited food availability; and pesticide use
2 (Johnson et al. 2010; FWS 2014a).

3
4 The western yellow-billed cuckoo requires structurally complex riparian habitats with tall
5 trees and a multi-storied vegetative understory. It rarely nests (2.5% of nests) in areas dominated
6 by tamarisk (Johnson et al. 2010; Schell 2005). In Arizona, western yellow-billed cuckoo occur
7 most often in sites dominated by native tree species and at lower numbers in habitats consisting
8 of mixed native or >75% tamarisk cover (Johnson et al. 2010). It forages almost entirely in
9 native riparian habitat, as the large caterpillars on which it feeds depend on cottonwoods and
10 willows and do not occur on tamarisk (FWS 2014a). It may be unreasonable to expect the Grand
11 Canyon to serve as functional breeding habitat for the western yellow-billed cuckoo due
12 inadequate riparian vegetation conditions (Schell 2005). Suitable habitat may have been limited,
13 as pre-dam floodplain terraces were neither abundant nor generally sufficiently wide in the
14 Grand Canyon.

15
16 The western yellow-billed cuckoo is known to occur at a number of sites in the lower
17 Grand Canyon near the Lake Mead delta (Figure 3.7-2). The riparian community at these sites is
18 primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in
19 these sites. However, drops in Lake Mead water levels lower the water table and stress the
20 vegetation at these sites. Surveys for this species at these sites resulted in 29 cuckoo detections in
21 2006 and no detections in 2007 (Johnson et al. 2008).

22 23 24 **Yuma Clapper Rail**

25
26 The Yuma clapper rail was listed as endangered under the ESA in 1967 (FWS 1967) and
27 is identified as an AZ-SGCN (AZGFD 2012). It inhabits marshes dominated by emergent plants.
28 Emergent plant cover is more important than the plant species or marsh size. Areas with high
29 coverage by surface water, low stem density, and moderate water depth are used for foraging;
30 sites with high stem density and shallower water near shorelines are used for nesting
31 (Reclamation 2008d). Generally, it is associated with dense riparian and marsh vegetation
32 dominated by cattails and bulrush with a mix of riparian tree and shrub species (NPS 2013e). It is
33 a casual summer visitor to marshy mainstem riparian habitats along the Colorado River below
34 Separation Canyon (Figure 3.7-2). These sightings are far from the species' breeding range on
35 the lower Colorado River (Gatlin 2013). Individuals were recorded in GCNP from 1996 to 2001.
36 The Yuma clapper rail was observed between Spencer Canyon (RM 246) and the Grand Canyon
37 National Park boundary (RM 227), with nesting confirmed in 1996. Individuals have also been
38 observed near Burnt Springs (near RM 260). It is not known whether cattail habitat is present in
39 sufficient quantities to support nesting (NPS 2013e). Yuma clapper rails feed on a variety of
40 aquatic and terrestrial invertebrates, and on small fish and amphibians. Plant matter (e.g., seeds
41 and twigs) comprises a minor component of its diet (Reclamation 2008d). Threats to rails come
42 from fluctuating flows during the breeding season (March–August), when there are eggs, less-
43 mobile young birds, or flightless adults in the molting season (August).

1 **3.7.5.4 Mammals**
2

3 The only threatened, endangered, or sensitive mammal species that may occur in riparian
4 areas within the action area is the spotted bat. The spotted bat is not federally listed but is
5 identified as an AZ-SGCN (AZGFD 2012). It is rarely encountered in Arizona, but may occur in
6 areas where cliffs and water sources are nearby. Most individuals are observed in dry, rough
7 desert shrublands or in pine forest communities. Roost sites are presumed to be crevices and
8 cracks in cliff faces (AZGFD 2003b). The spotted bat is active in winter, particularly if
9 hibernacula have low humidity. It tends to be relatively solitary but may hibernate in small
10 clusters (AZGFD 2003b). Dominant prey items are moths, but also include June beetles and
11 sometimes grasshoppers that are taken while on the ground (AZGFD 2003b).
12
13

14 **3.8 CULTURAL RESOURCES**
15

16 Cultural resources are defined as physical entities or cultural practices and are typically
17 categorized as archeological resources, historic and prehistoric structures, cultural landscapes,
18 traditional cultural properties, ethnographic resources, and museum collections. Many natural
19 resources, such as plants and plant gathering areas, water sources, minerals, animals, and other
20 ecological resources, are also considered cultural resources, as they have been integral to the
21 identity of Tribes in various ways. The physical attributes of cultural resources are often
22 nonrenewable, especially concerning ancestral archaeological sites with few exceptions, and the
23 primary concern for managers is to minimize the loss or degradation of culturally significant
24 material.
25

26 Historic properties are a subset of cultural resources. Historic properties are defined as
27 those cultural resources that meet the eligibility criteria for listing on the *National Register of*
28 *Historic Places* (NRHP) and are considered “significant” resources that must be taken into
29 consideration during the planning of federal projects. Historic properties can be either manmade
30 or natural physical features associated with human activity and, in most cases, are finite, unique,
31 fragile, and nonrenewable. For example, historic properties can include traditional cultural
32 properties (TCPs), which are properties that are important to a community’s practices and beliefs
33 and that are necessary for maintaining the community’s cultural identity. Historic properties can
34 also include certain archeological sites or historic districts containing multiple interrelated
35 archaeological or historic elements. Under the National Historic Preservation Act (NHPA;
36 P.L. 89-665, as amended by P.L. 96-515) and the American Indian Religious Freedom Act
37 (P.L. 95-341), federal agencies are also required to consider the effects of their actions on sites,
38 areas, and other resources (e.g., plants) that are of cultural and religious significance to Native
39 Americans, Native Alaskans, and Native Hawaiians. Native American graves and burial grounds
40 are protected by the Native American Graves Protection and Repatriation Act (P.L. 101-601).
41 Also under the Grand Canyon Protection Act of 1992, cultural resources were identified as one
42 of the resources that must be protected, mitigated, and improved, where possible. The NHPA is
43 the overarching law concerning the management of historic properties. Numerous other
44 regulatory requirements pertain to cultural resources and are presented in Chapter 1.
45

1 Historic properties on federal lands are managed primarily through the application of
2 laws, orders, and policies. Guidance on the application of these laws is provided through various
3 means. Most federal agencies have published guidance on how to appropriately manage historic
4 properties on their lands. Guidance for historic property management in all NPS units comes
5 from the *NPS Management Policies 2006* (NPS 2006d) and NPS-28, *Cultural Resource*
6 *Management Guideline* (NPS 1998). Specific guidance for GCNP and GCNRA is provided
7 through both parks' General Management Plan and the GCNP Colorado River Management
8 Plan. Additional direction in GCNP is derived from the 2010 Foundation Statement and, for
9 GCNRA, the 2015 Foundation Statement. The Reclamation policy concerning cultural resources
10 is outlined in Policy LND P01, which ensures compliance with existing cultural resource law and
11 Directives and Standards LND 02-01, which identifies Reclamation's roles and responsibilities
12 as they relate to cultural resources.
13

14 The management of historic properties along the Colorado River in GCNP and GCNRA
15 is guided by several agreements that resulted from environmental studies concerning the
16 operation of Glen Canyon Dam and the management of the resources in the two national park
17 units. The 1995 EIS for operations of Glen Canyon Dam (Reclamation 1995) was accompanied
18 with the signing of a Programmatic Agreement (PA) in 1994. The agreement was between the
19 Arizona State Historic Preservation Office, Reclamation, NPS, the Hopi Tribe, Hualapai Tribe,
20 Kaibab Paiute Tribe, Navajo Nation, Shivwits Paiute Tribe, and Zuni Pueblo. The 1994 PA
21 addressed management of over 300 cultural resources that could be affected by dam operations.
22 These sites included the 323 sites that comprise the Grand Canyon River Corridor Historic
23 District. As agreed to by the signatories of the 1994 PA, a new PA is being developed in
24 conjunction with the LTEMP EIS based on research and monitoring along the river and the
25 resulting new information accumulated since 1996. This draft PA currently is being developed as
26 allowed in 36 CFR 800.14 b(1) (ii) when effects on historic properties cannot be fully
27 determined prior to approval of the undertaking. The draft PA outlines general and specific
28 measures Reclamation (as lead federal agency for operation of Glen Canyon Dam and with
29 responsibility for the mitigation of effects from dam operations) and the NPS will take to fulfill
30 their responsibilities regarding the protection of historic properties under the NHPA.
31

32 In 2011, Reclamation conducted two EAs to study the effects of HFEs and control of
33 nonnative fish. These EAs developed Memorandum of Agreement (MOA) documents for
34 potential adverse effects under NHPA for these specific undertakings. The Area of Potential
35 Effect (APE) for the HFE EA MOA included 19 sites that could be directly inundated by flows
36 as well as the Lees Ferry Historic District and the Grand Canyon River Corridor Historic
37 District. The Nonnative Fish Control EA looked at methods for controlling nonnative fish, and
38 the resulting MOA from that action included measures to address potential adverse effects to
39 Tribal TCPs. The new PA being developed for operations of Glen Canyon Dam under LTEMP
40 incorporates measures to monitor and address the effects of HFEs and nonnative fish control, and
41 when executed will thereby replace both the HFE and Nonnative Fish Control MOAs.
42

43 The NHPA applies to federal undertakings and undertakings that are federally permitted
44 or funded. The regulations implementing Section 106 of the NHPA, codified at 36 CFR 800,
45 defines the process for identifying historic properties and for determining if an undertaking will
46 adversely affect those properties. The regulations also establish the processes for consultation

1 among interested parties, the agency conducting the undertaking, the Advisory Council on
2 Historic Preservation, and the SHPO, and for government-to-government consultation between
3 federal agencies and American Indian Tribal governments. The NHPA, in Section 106, addresses
4 the appropriate process for mitigating adverse effects. The implementing regulations also address
5 the process for mitigating adverse effects.

8 **3.8.1 Area of Potential Effect**

9
10 NHPA compliance includes the definition of an APE, which is equivalent to “the affected
11 environment” for cultural resources and is defined in 36 CFR 800.16(d) as:

12
13 Area of potential effects means the geographic area or areas within which an
14 undertaking may directly or indirectly cause alterations in the character or use of
15 historic properties, if any such properties exist. The area of potential effects is
16 influenced by the scale and nature of an undertaking and may be different for
17 different kinds of effects caused by the undertaking.

18
19 The term “undertaking” in NHPA parlance equates to the “proposed action” for NEPA.
20 The undertaking is the proposed operation of Glen Canyon Dam for a period of 20 years under
21 the LTEMP including any related non-flow actions that could affect historic properties. Dam
22 operations under the LTEMP are anticipated to continue to include recurring flows that may fully
23 utilize the capacity of the powerplant turbines and bypass tubes (i.e., HFEs). The undertaking
24 may include LTEMP activities other than Glen Canyon Dam operations (i.e., non-flow actions
25 such as vegetation management, nonnative fish monitoring, and fish control). Longitudinally, the
26 APE for the LTEMP undertaking associated with Glen Canyon Dam operations includes the
27 active channel of the Colorado River in Glen, Marble, and Grand Canyons from Glen Canyon
28 Dam to the western boundary of GCNP near Pearce Ferry. Laterally, the APE extends from the
29 Colorado River both horizontally and vertically to varying extent based on the specific
30 operational, topographic, and natural processes at each location. The variable upslope extent of
31 the APE primarily depends on the distribution of sandbars and the potential for fine sediment
32 redistribution by canyon winds under the prevailing flow regimes of the Colorado River, as
33 described in this DEIS. The APE includes areas that are directly and indirectly affected by the
34 flow of the Colorado River, and active wind processes. Historic properties along the river
35 corridor may be found within the following categories of geologic deposits: (1) post-dam
36 Colorado River alluvium that is composed of fine sediment; (2) pre-dam Colorado River
37 alluvium that is composed of fine sediment; (3) active windblown deposits; and (4) coarse-
38 grained Colorado River alluvial deposits. Other types of historic properties that could be affected
39 include TCPs that are described in Section 3.9. The APE and the undertaking for this LTEMP
40 DEIS are defined in full in Appendix I.

41
42 Effects to cultural resources were defined, following 36 CFR 800.16(i), as any alteration
43 to the characteristics of a historic property qualifying it for inclusion in or eligibility for the
44 NRHP. Direct, indirect, or cumulative effects were defined using a combination of the Council
45 of Environmental Quality regulations at 40 CFR 1508.8 and the criteria of adverse effect at
46 36 CFR 800.5. Direct effects are reasonably foreseeable changes in the integrity of properties

1 believed to be caused by the proposed action and that are likely to occur at the same time and
2 place; indirect effects are defined as those reasonable foreseeable effects caused by the
3 undertaking that may occur later in time, be further removed in distance, or be cumulative.
4

5 There are a number of ways in which dam operations may affect cultural resources
6 including the periodicity of inundation and exposure, changing vegetation cover, streambank
7 erosion, slumping, and influencing the availability of sediment. Direct and repeated
8 inundation/exposure may affect resources such as the Spencer Steamboat, which is in the active
9 channel (Figure 3.8-1), or Pumpkin Springs, a TCP along the bank that is subject to inundation
10 during high flows (e.g., equalization flows and HFEs). Streambank erosion, slumping, flow-
11 related deposition, and indirect effects of deposition may affect cultural resources contained
12 within terrace contexts in proximity to inundated areas. Fine sand or sediment can be blown from
13 flow-deposited source areas and deposited on cultural sites (Figure 3.8-2). The effects of
14 deposition or erosion may be negative or positive depending on the nature of the site. One
15 important recent finding is that sandbars created by high-flow events at Glen Canyon Dam can
16 provide sources of wind-blown sand that can cover archaeological sites as well as anneal, or
17 reverse, the formation of gullies (Sankey and Draut 2014). In this context, changes in dam
18 operations can affect erosion rates on archaeological sites. In addition, bank deposition and
19 aeolian transport of sediment can affect the character of other types of TCPs.
20

21 USGS and GCMRC developed a system for classifying the geomorphic settings of
22 archaeological sites, based on the degree to which they can receive windblown sand from
23 deposits from recent controlled floods, to address how cultural sites are linked to modern river
24 processes (Sankey, Bedford et al. 2015). There are 394 river-corridor archaeological sites in
25 Glen, Marble, and Grand Canyons. As of January 2015, USGS had examined 358 sites in GCNP
26 to establish the potential effects of windblown sands at these locations. This review did not
27 include a small number of sites in GCNRA, which are expected to be classified by GCMRC in
28 2016. Additional screening criteria were developed by the joint lead agencies to further review
29 sites for consideration in the PA process.
30

31 Based on a review of sites inventoried and subsequently monitored pursuant to the
32 1994 PA and additional analysis in preparation of the new PA, 140–220 sites could be affected
33 by dam operations or other aspects of the undertaking based on the USGS and GCMRC
34 classification system described above. Additional information including inventory and
35 monitoring, data recovery activities, and completion of determinations of eligibility for sites
36 along the river are continuing to provide up-to-date information on sites potentially affected.
37
38

39 **3.8.2 Description of Cultural Resources and Site Types**

40
41 Glen, Marble, and Grand Canyons are significant for their human history and their
42 ongoing roles in the lives and traditions of today's American Indians of the Colorado Plateau.
43 Archaeologists generally divide the nearly 12,000 years of human history of the Grand Canyon
44 region into six broad periods: Paleoindian, Archaic, Formative, Late Prehistoric, Protohistoric,
45 and Historic. The human story is represented in each of these periods along the Colorado River



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FIGURE 3.8-1 Spencer Steamboat (Photo by Susanna Pershon, Submerged Cultural Resources Unit, NPS)



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FIGURE 3.8-2 A Roaster Site (Prehistoric Food Preparation Location) in a Grand Canyon Dune

1 from Glen Canyon Dam to Lake Mead. What follows is a description of the Western Euro-
2 American (i.e., non-Tribal) view of the types of cultural resources and the timeframes into which
3 those resources fall (see Section 3.9 for the Tribal view of the history and meaning of the Grand
4 Canyon).

7 **3.8.2.1 Archaeological Resources**

8
9 Archaeological resources are defined as “any material remains or physical evidence of
10 past human life or activities which are of archeological interest, including the record of the
11 effects of human activities on the environment. They are capable of revealing scientific or
12 humanistic information through archeological research” (NPS 2006b).

13
14 Archaeological research along the Colorado River corridor in Glen and Grand Canyons
15 began in 1869 with the first report of ruins by John Wesley Powell (Powell 1875). In the early
16 1930s, professional archeology began in the region with Julian Steward’s work in the Lees Ferry
17 area (Steward 1941). Later, in 1953, Walter Taylor began work along the Colorado River in
18 Grand Canyon (Taylor 1958). From 1956 through 1963, one of the largest single archeological
19 salvage projects in the United States was undertaken in the Glen Canyon region to mitigate for
20 the construction of Glen Canyon Dam (Jennings 1966). Because dam construction predated the
21 passage of NHPA in 1966, pre-dam mitigation was conducted under the auspices of the Historic
22 Sites Act of 1935 and then the Reservoir Salvage Act of 1960. Pre-dam mitigation was
23 performed by the University of Utah, the Museum of Northern Arizona, and the NPS.

24
25 For the pre-dam mitigation effort, archeological salvage was limited to the north and
26 south sides of the Colorado River above the dam up to Hite, Utah, and to portions of the San
27 Juan River. No survey and excavation occurred below the site of Glen Canyon Dam. A complete
28 archaeological inventory of the river corridor, encompassing all traversable terrain between Glen
29 Canyon Dam and Separation Canyon from the river up to and including pre-dam river terraces,
30 was completed in 1991 for the 1995 Glen Canyon Dam EIS (Fairley et al. 1994). This and
31 subsequent survey efforts have documented nearly 500 properties in the near-shore environment
32 of the river from Glen Canyon Dam to Lake Mead.

33
34 To help understand what they encounter, archaeologists divide human history into
35 sequential periods on the basis of distinctive changes in technology, subsistence practices, and/or
36 sociopolitical organization. Below are descriptions of these periods and the types of
37 archaeological resources typical for those periods that are found along the Colorado River from
38 Glen Canyon to Lake Mead. The following discussion is based on chronological divisions in
39 general use in the American Southwest, as modified for the Grand Canyon region by Fairley
40 (2003). Details of individual sites and determinations concerning which sites could be affected
41 and how many potential effects may be mitigated will be addressed through the PA process.

42
43
44 **PaleoIndian Period (10,000–6,000 BC).** Sites from this time period are characterized by
45 very distinctive spear points used to hunt large animals, such as mammoth, sloth, bear, and wolf.
46 These distinctive spear points are found across Arizona, New Mexico, and Texas. Three

1 locations within GCNP have yielded fragmentary spear points dating from this Clovis and
2 Folsom tradition. Three additional sites in western Grand Canyon are also believed to contain
3 Paleoindian artifacts. Within GCNRA, Paleoindian points have been found at six sites. Five were
4 found in the northernmost part of the park and one west of Lees Ferry. These sites reflect
5 characteristics of the Clovis, Folsom, and Plano technological complexes of the Paleoindian
6 period.

7
8
9 **Archaic Period (6,000–500 BC).** Sites dating from this time period contain smaller, but
10 distinctive, projectile points (dart points). There is also evidence of experimentation with
11 cultivating plants. Artifacts include small processing stones such as one-handed manos and
12 grinding slabs, and abundant plant remains found in a trash context. These items suggest
13 increased activities toward plant processing and more reliance on plants as a food source than
14 was evident during the Paleoindian Period. Elaborate multicolored rock art and split-twig
15 figurines found in cave settings are hallmarks of the Grand Canyon Archaic Period. Archaic
16 Period sites include hunting blinds, lithic scatters at meadow edges and water holes, temporary
17 camps, rock art, and split-twig figurine caches (Figure 3.8-3). Another distinctive aspect of the
18 Archaic cultural history along the Colorado River corridor in GCNRA during the Archaic Period
19 is a certain distinctive style of petroglyphs known as the Glen Canyon Linear Style
20 (Figure 3.8-4).

21
22
23 **Formative: Basketmaker Period (500 BC–700 AD).** This period is distinguished by
24 extensive use of baskets, sandals, and textiles, and some important technological advancements
25 such as the development of the bow and arrow and the beginnings of pottery manufacture.
26 Habitations are often single pit houses with bell-shaped pits dug for storage. There is evidence of
27 increased reliance on cultivated plants, primarily corn and squash. Western Grand Canyon has
28 the largest concentration of sites from this time period within Grand Canyon.

29
30
31 **Formative: Ancestral Puebloan and Cohonina (700–1300 AD).** Typical of these
32 periods are the distinctive masonry structures and apartment-like dwellings (pueblos) that the
33 ancestral Puebloan people lived in during this time (Figure 3.8-5). This period is characterized by
34 more permanent settlements and reliance on agriculture—most notably beans, corn, squash, and
35 cotton—and pest-resistant storage features. Evidence of craft specialization, including distinctive
36 ceramic designs, allows archaeologists to attribute occupation dates to sites and associated
37 deposits with specific cultural groups. The majority of GCNRA and GCNP sites are of Puebloan
38 age. Puebloan people were occupying the area north (Virgin Branch), south and east (Kayenta
39 Branch) of the Colorado River during the Formative Period. Modern Puebloan Indians consider
40 themselves to be descendants of these ancestral people.

41
42 The Cohonina people were a distinctive cultural group living in a discreet area running
43 east to west between the San Francisco Peaks and the Grand Wash Cliffs and north to south from
44 the Colorado River to the Mogollon Rim during AD 700–1175. Both their home sites and
45 distinctive ceramics identify them as culturally separate from the neighboring Puebloan groups.
46 Cohonina sites in the Grand Canyon consist of settlements located on both sides of the river, use



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FIGURE 3.8-3 An Archaic Period Site on the Colorado River in GCNP



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FIGURE 3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA



**FIGURE 3.8-5 Puebloan Era Architecture
along the Colorado River in GCNP**

of multiple areas for resource procurement, and small camps or hamlets. The Hopi, Hualapai, and Havasupai consider themselves descendants of the Cohonina archaeological culture.

Late Prehistoric (1250–1540 AD). Current evidence indicates that ancestral Puebloan populations moved out of the canyons as the Southwest became drier and cooler in the 13th century, while people from the west continued to expand their land base and further incorporated the canyon into their seasonal hunting and gathering cycles. These groups were less sedentary and less reliant on crops, and they lived in smaller camps, built brush structures, and used communal roasting features and small clusters of fire pits. The ancestral Pai and Southern Paiute were well established in the canyon during this time. Archaeologists have identified different pottery types of both local and imported varieties that are characteristic of cultural transitions during this period.

Protohistoric Period (1540–1776 AD). The Protohistoric Period contains evidence of incursions by white settlers and miners: European explorers, specifically Spanish expeditions in search of gold and wealth, but with an ancillary mission of converting native people along the way to Christianity. Although the experience of indigenous groups with these contacts varied widely, much of the region immediately in the vicinity of the Grand Canyon and Colorado River was not greatly affected, especially in the western canyon country. Growing familiarity with

1 horses and items of European manufacture was likely, however. This period witnessed the
2 greatest expansion of the Pai and Southern Paiute into the Grand Canyon and along the river
3 corridor. Archaeological evidence suggests that the ancestral Puebloan peoples who had
4 previously occupied the canyon had already shifted settlements to the east by this time.
5
6

7 **3.8.2.2 Historic Resources**

8

9 Historic resources represent the period from 1776 to the present. The period is
10 characterized by incursions by Europeans and later by Euro-American exploration along the
11 Colorado River. In GCNRA, the Dominguez-Escalante Expedition in 1776 crossed the Colorado
12 River at what is now Lees Ferry. That same year, Fr. Francisco Garces led a separate Spanish
13 expedition from the southwest, up the lower Colorado River, and then overland; he visited
14 Hualapai and Havasupai settlements in the western Grand Canyon area, even relying on Hualapai
15 guides for part of his journey (Coues 1900). Euro-American expeditions include the 1869 Powell
16 expedition and the 1889–1890 Stanton expedition, among others. The historic period ends with
17 the engineering tests for the Marble Canyon Dam site in the late 1950s.
18

19 During the 19th century, in response to the growing pressures brought by the increasing
20 numbers of European and Euro-American settlers, some indigenous groups retreated to smaller
21 territories, formed aggregate villages, and used side canyons as places of refuge. Small bands of
22 Hualapai and Southern Paiute wishing to avoid conflict with the U.S. Army stayed in the western
23 canyon, largely out of reach of soldiers on horseback. Havasupai Indians lived at Indian Garden
24 along the Bright Angel Trail and in a permanent settlement in the South Rim Village area.
25 Southern Paiute bands used large areas across the Tuweep Valley for habitation and resource
26 procurement. Navajo lived along the south, east, and north rims and within the canyon for
27 seasonal and religious purposes. Ultimately, however, the designation of permanent reservations
28 by treaty or executive order led to the forced or coerced relocation of Tribes out of vast areas of
29 their ancestral territories.
30

31 Native American sites from the Historic Period in the Grand Canyon are characterized by
32 a blending of the old and traditional with the new and innovative. Pottery and tools made of
33 stone and bone are found along with metal and glass projectile points. Metal buckets, kitchen
34 cutlery, and canned food and beverage containers are found in at such sites.
35

36 Types of historic resources found along the mainstem of the Colorado River include
37 artifact caches and isolated occurrences, abandoned boats, dwellings, remnants of mining
38 operations, camps, ranching, features related to dam site development, trails, inscriptions, and
39 plaques. Historic era American Indian use of areas along the Colorado River is evidenced from
40 numerous locations along the riverbanks. Remnants of hogans, extraction sites (i.e., mines) and
41 small camps are remnants of this time. Of the total number of identified archeological sites along
42 the mainstem Colorado River, at least 71 have a Euro-American historical component (Fairley
43 et al. 1994; Reclamation 1995).
44

45 In GCNRA, Lees Ferry was settled by John D. Lee who established one of the primary
46 river ferry crossings at this location (Figure 3.8-6). The remains of the Charles H. Spencer



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FIGURE 3.8-6 Lees Ferry Historic District Located in GCNRA

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3.8.2.3 Cultural Landscapes

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As defined in the NPS *Cultural Resource Management Guideline* (NPS 1998), cultural landscapes are settings that humans have created in the natural world. They are intertwined patterns of things both natural and constructed, expressions of human manipulation and adaptation of the land (see Section 3.9 for a description of the Tribal perspective on cultural landscapes). One type of cultural landscape, the historic vernacular landscape, is represented in the Colorado River corridor at both Lees Ferry and Phantom Ranch.

At Lees Ferry, the Colorado River briefly flows free of canyon walls, historically the only place in over 400 mi that it could be accessed on both banks by wagon. This natural attribute has

1 influenced the site's history for 130 years. Today, historic buildings and a cemetery, shade trees,
2 an orchard, fields, trails, and dugways carved into the river bluffs combine with more
3 contemporary structures to illustrate the site's use as a farm and a vital ferry link between
4 settlements in Utah and Arizona. The establishment of USGS gaging stations that are used today
5 to fulfill terms of the Colorado River Compact, a dude ranch, and an access point for river
6 runners are also present at Lees Ferry.

7
8 At Phantom Ranch, major side canyons and perennial tributaries provided the natural
9 context for what would become the nexus of a cross-canyon corridor and the most popular site in
10 the inner canyon. Here, historic guest lodges and NPS buildings, livestock structures,
11 cottonwood trees, a campground, bridges across Bright Angel Creek and the Colorado River, and
12 a network of trails document 80 years of recreational activity at the very bottom of the Grand
13 Canyon.

14
15 On a broader scale, the entire river corridor can be viewed as a cultural landscape in
16 which American Indians for millennia have farmed, hunted, gathered plants and minerals, and
17 performed rituals. Ancient trails, remnants of stone structures, traces of fields, and prayer objects
18 enshrined in travertine and salt are enduring evidence of a subtly altered landscape. Integral to
19 this landscape are the animals, plants, and minerals traditionally used and valued by American
20 Indians. Aspects of American Indian cultural landscapes are discussed in Sections 3.8.2.4 and
21 3.9 and throughout this document.

22 23 24 **3.8.2.4 Traditional Cultural Properties and Ethnographic Resources**

25
26 "A traditional cultural property, then, can be defined generally as one that is eligible for
27 inclusion in the NRHP because of its association with cultural practices or beliefs of a living
28 community that (a) are rooted in that community's history, and (b) are important in maintaining
29 the continuing cultural identity of the community" (Parker and King 1990). Like historic
30 properties, TCPs are given consideration under the NHPA of 1966, as amended. During research
31 related to Glen Canyon Dam operations and sponsored by Reclamation, five Tribes identified
32 cultural resources of importance to them in the river corridor that are TCPs. This includes Grand,
33 Marble, and Glen Canyons, and the Colorado and Little Colorado Rivers.

34
35 Ethnographic resources often overlap with archaeological sites and other resources of
36 ongoing traditional cultural importance. "Park ethnographic resources are the cultural and natural
37 features of a park that are of traditional significance to traditionally associated peoples. These
38 peoples are the contemporary park neighbors and ethnic or occupational communities that have
39 been associated with a park for two or more generations (40 years), and whose interests in the
40 park's resources began before the park's establishment" (NPS 2006d).

41
42 American Indian people consider the broader area of Glen and Grand Canyons to be of
43 traditional, even sacred, importance (Hopi CPO 2001; Dongoske 2011a; Maldonado 2011;
44 Coulam 2011). More information regarding the perspective of the canyons as a TCP is presented
45 in Section 3.9. This information has been furnished by interested Tribes at the request of
46 Reclamation and NPS, in order to aid in public understanding of their concerns.

1 **3.9 TRIBAL CULTURAL RESOURCES**
2

3 The Colorado River, as it flows through the Glen Canyon, Marble Canyon, and Grand
4 Canyon (Canyons), has a prominent place in the traditional cosmology of the indigenous peoples
5 of the Southwest and continues to have an important place in contemporary American Indian
6 cultures and economies. The Hopi, Havasupai, Hualapai, Navajo, Zuni, Southern Paiute, and
7 Fort Mojave Tribes all have strong cultural ties to the Colorado River and the Canyons, and these
8 Tribes have provided information on the determination of eligibility of the Colorado River and
9 the Canyons as TCPs.

10
11 For these Tribes, the Canyons are more than just beautiful scenery. The Canyons are
12 alive. The Colorado River, the canyons it has carved, and the resources it supports over a vast
13 landscape are all considered sacred to these Tribes. Many Tribal members regard the Canyons as
14 sacred space, the home of their ancestors, the residence of the spirits of their dead, and the source
15 of many culturally important resources. They are important to the genesis of the Tribes and to
16 their contemporary ways of life rooted in traditions engendered by those experiences. Many
17 Tribes see themselves as connected to the Colorado River and its Canyons and as stewards over
18 the living world around them, including water, earth, plant life, and animal life.

19
20 Although archaeological data can provide significant evidence of past lifeways, it tells
21 only part of the story. Within this landscape are culturally important natural resources and
22 significant cultural landscapes that serve as the settings for Tribal histories and spiritual
23 narratives. Many Tribes have adapted their role as stewards to the modern environment by
24 submitting documentation to support their contention that portions of the Colorado River and the
25 canyons through which it flows should be considered a TCP. Various elements within this
26 boundary are considered contributing elements to the TCP (Hopi CPO 2001; Dongoske 2011b;
27 Maldonado 2011; Coulam 2011). This documentation provides information supporting a
28 determination of the eligibility of the TCP and many, but not all, associated elements located in
29 or along the Colorado River for listing on the *National Register of Historic Places*. These TCPs
30 have been determined eligible by the Arizona SHPO (Reclamation 2011a). Some of the elements
31 of these TCPs have been disclosed and other elements are considered confidential, but all are
32 considered significantly important to the Tribes. Traditional narratives of Tribal history and
33 understandings of traditional landscapes, combined with archaeological data, provide a
34 comprehensive representation of American Indian lifeways. The following discussion of the
35 importance of the Canyons and the Colorado River for the American Indian Tribes of the region
36 and their monitoring of these resources was written, for the most part, by the LTEMP DEIS staff
37 and edited and approved by Tribal representatives from each Tribe. Tribal representatives from
38 the Hopi, Hualapai, and the Zuni contributed their own text.

39
40
41 **3.9.1 Havasupai**
42

43 The Havasupai Tribe and Tribal members have a history interwoven with that of GCNP
44 since creation of the park from within the Havasupai aboriginal territory. Members of the
45 Havasupai Tribe have access to locations of importance within GCNP guaranteed by the
46 1919 Act establishing Grand Canyon National Park (40 Stat. 1175, 1919) and the 1975 Grand

1 Canyon Enlargement Act (88 Stat. 2089, 1975). The members of the Havasupai Tribe have
2 statutory rights of access to areas on public lands, including any sacred or religious places or
3 burial grounds, native foods, paints, materials, and medicines (16 USC 228i(c)).
4

5 The Havasupai view everything in and around the Grand Canyon as sacred in all aspects
6 of their cultural, spiritual, and traditional life (Reclamation 1995). The Havasupai were
7 signatories to the 1994 PA (Reclamation 1994), yet chose not to participate in the GCDAMP.
8 The Tribe works closely with the NPS for protection of cultural sites, historic locations, and
9 water resources. They are a member of the Native Voices on the Colorado River, a group that
10 works with the Grand Canyon Colorado River Outfitters Association to increase understanding
11 of Tribal relationships with the Grand Canyon from their own perspective (NVCR undated).
12 Members of the Havasupai Tribe have worked as interpreters in GCNP.
13
14

15 **3.9.2 Hualapai**

16
17 The Hualapai consider the Grand Canyon and Colorado River region a great cultural
18 landscape, especially the stretch from the Little Colorado River downstream to the confluence of
19 the Colorado with the Bill Williams River in west-central Arizona. As of 2011, 28 places along
20 the river are periodically monitored, in addition to an emphasis on the Colorado River itself and
21 its tributary canyons, which the Hualapai also consider TCPs (Jackson-Kelly et al. 2011).
22 Furthermore, many of the ancestral archaeological sites along the river are cited as TCPs, as
23 well, but are not necessarily monitored due to difficult or obscure access and the fact that they
24 are located in fragile contexts where periodic monitoring would simply result in undesirable
25 impacts in and of itself. Monitoring activities also include the consideration of ethnobotanical
26 resources. When considering the intricacies of the Hualapai people's historical, cultural, and
27 spiritual relationship to the canyon, it is very difficult and even imprudent to attempt to assign a
28 number to quantify significant Hualapai cultural resources along the complex landscape of the
29 Colorado River corridor. For the most part, an evaluation of the "health" of these places is
30 essentially a holistic response to not simply a defined point on the land, but more of the spiritual
31 well-being one feels when standing there, as if the land was expressing its own condition through
32 the person charged with evaluating that condition. This could include the prevalence of visitors
33 and the availability of privacy, the incidence and cause of erosion, the quality of water, or any
34 number of other factors. The Hualapai's participation in the monitoring and assessment of
35 cultural and natural resources throughout the Grand Canyon extends back to the early 1990s and
36 has been a consistent presence in management decisions.
37

38 The Colorado River and its Canyons are significant spiritual and physical landmarks for
39 the Hualapai. The Hualapai consider the river the backbone, or *Ha'yidada*, of the landscape and
40 to have healing powers (NPS 2011). Today, this is symbolized by its placement in the center of
41 the Hualapai seal (Hualapai Tribe 2013). The Hualapai worldview holds that the Colorado River
42 provides a life connection to the Hualapai as it flows through the landscape connecting the
43 Canyons and the riparian ecosystems that sustain the Tribe. *Ha'thi-el* (Salty Spring), a sacred
44 spring within the Canyons, contains a petroglyph site that tells of the creation of the Hualapai
45 and other Pai peoples (HDCR 2010).
46

1 The Hualapai have occupied and used the lands and waters lying within their ancestral
2 territory, including their present reservation, since time immemorial. The Hualapai traditionally
3 benefited from both hunter-gatherer and agricultural subsistence practices. Throughout the year
4 the people collected various plant foods that were available depending on the season, such as
5 agave in the spring, grass seeds in summer, and piñon in the uplands in the fall. Access to these
6 resources often involved moving camps seasonally for closer proximity. Important cultural and
7 spiritual lessons were passed down from elder to child during these recurring seasonal rounds
8 (HDCR 2010). Plants were important not only for food but also for medicine and for materials
9 for making baskets, cradleboards, shelter, and other useful items.

10
11 Although permanent water sources were sometimes scarce over large areas, the Hualapai
12 were able to establish gardens and small fields in optimal locations, including along the Colorado
13 River. Typical crops include corn, beans, and squash, as with other Tribes in the region. Seeds
14 were often traded with neighboring people, especially the Mojave, Havasupai, and Hopi. Near
15 springs, small terraces were established where water could be diverted. In larger streams, they
16 made use of alluvial terraces that flooded over during spring runoff, enriching the soil as well as
17 providing moisture for young seedlings. Irrigation channels were sometimes used to augment
18 runoff and create more dependable watering systems, such as along the Big Sandy River. Unique
19 to certain locations in the western Grand Canyon and along the lower Colorado River, such as
20 around Pearce Ferry and Willow Beach, actual floodwater farming was practiced, similar to
21 Ak-Chin strategies practiced in southern Arizona.

22
23 Larger game animals included mule deer, bighorn sheep, and pronghorn antelope, but
24 rabbits and other small game were also important. Game animals provided materials for shelter,
25 clothing, tools, weapons, and ceremonial objects, in addition to being vital food sources. The
26 Hualapai were considered excellent hunters and commonly traded hides and dried meat with
27 their neighbors in virtually every direction, including across the river to the north. This pattern of
28 subsistence continued for many centuries.

29
30 Although sporadic contact with European (mainly Spanish) explorers started in 1776, it
31 was not until the mid-19th century that Hualapai people had extensive dealings with Euro-
32 American settlers. At first, these interactions appeared to be fairly amicable, but as the
33 newcomers' hunger for land, minerals, water, and grass for livestock grew, trouble ensued by the
34 mid-1860s. After a period of conflict with these intruding Euro-American miners, ranchers, and,
35 inevitably, the U.S. Army, a truce was forged in 1868. Most Hualapai were persuaded to
36 congregate at Camp Beale Springs near present-day Kingman, Arizona, where they maintained
37 relatively good relations with the commanding officer, Captain Thomas Byrne (Casebier 1980).
38 This eventually led to a number of Hualapai men joining the Army as scouts for General George
39 Crook in 1873, during which time they performed admirably, according to Crook's own words.
40 However, once their service was no longer required, in 1874, many of the Hualapai were
41 removed from their homeland and forced into an internment camp at La Paz, Arizona, near the
42 present-day town of Ehrenberg. Many Hualapai perished from malnutrition, excessive heat, and
43 disease while interred at the camp, and those that were eventually released returned to their
44 homeland to find it irrevocably altered by the rush of Euro-American migration. Only those that
45 lived in the most remote and rugged canyons near the Colorado River avoided this ordeal. The

1 Hualapai commemorate the march to La Paz, and this tragic period of their history, through an
2 annual relay run known as the La Paz Run (HDCR 2010).

3
4 Finally, in 1883, the Hualapai Reservation was established by executive order. It
5 comprised just a fraction of their original territory, but included 108 miles of the Colorado River
6 country and was at least part of their ancestral homeland. Evidence of their occupancy, use, and
7 ownership of their ancestral territory is contained in numerous and widespread archaeological
8 sites, family and Tribal records, oral traditions, and legends, and is embedded in the names of
9 landmarks and sacred places throughout the Canyons and surrounding areas (Reclamation 1995).
10 The Hualapai believe they are entrusted with the responsibility of caring for the land within their
11 ancestral homeland, both on and off the reservation, and are actively involved in preservation
12 activities and environmental stewardship throughout the Colorado River drainage.

13
14 The Hualapai participated in the development of the 1995 EIS (Reclamation 1995) as a
15 Cooperating Agency and as a PA signatory. At that time, a total of 18 cultural resource sites
16 were identified within the Canyons as archaeological sites and/or traditional cultural places
17 associated with the Tribe, although many more have been identified since then. In addition,
18 46 culturally significant plant species were identified within the river corridor.

19
20 Currently, the Hualapai are active members of the Adaptive Management Working Group
21 (AMWG) and the Technical Work Group (TWG), and they participate in the monitoring and
22 assessment of cultural and natural resources throughout the Grand Canyon, using a combination
23 of traditional ecological and cultural knowledge and modern survey techniques
24 (Jackson-Kelly 2008).

25
26 Hualapai monitoring programs have identified a number of issues that are negatively
27 affecting Hualapai archaeological sites, ethnobotanical resources, and other TCPs along the
28 Colorado River corridor. These include the disruption of riverine ecology due to fluctuating river
29 flows resulting from Glen Canyon Dam operations, and the related increase in human activity,
30 such as trailing and camping on beaches near ancestral sites. The dramatic increase in the
31 number of boaters and recreationists since the early days of river running is always a matter of
32 concern, as evidenced by occurrences of artifact piling, trail erosion, and the occasional
33 discovery of displaced artifacts and even human remains. The long-term trend of these
34 phenomena presents challenges in preserving the integrity and significance of fragile and
35 nonrenewable resources.

36
37 In April of 2010, Mr. Wilfred Whatoname, Sr., the Chairman of the Hualapai Tribe, sent
38 a letter of testimony to the Natural Resources Committee Joint Oversight Field Hearing, entitled
39 “On the Edge: Challenges Facing Grand Canyon National Park.” The letter requested assistance
40 in the restoration of funds for monitoring of Tribal resources and reiterated the Hualapai Tribe’s
41 commitment to preserving its natural and cultural resources (Whatoname 2010). The Hualapai
42 are also members of Native Voices on the Colorado River (NVCR undated). The Tribe is a
43 Cooperating Agency for the preparation of this LTEMP DEIS and has continued to develop,
44 refine, and expand its program of monitoring cultural and natural resources along the river,
45 including further implementation of traditional ecological knowledge.

1 **3.9.3 Southern Paiute Tribes**
2

3 The Southern Paiute Tribes that have ties to the region and who are most directly tied to
4 the project area include the Kaibab Band of Paiute Indians; the Paiute Indian Tribe of Utah,
5 which consists of five bands of Southern Paiute (Cedar Band, Indian Peaks Band, Kanosh Band,
6 Koosharem Band, and Shivwits Band); and the San Juan Southern Paiute. The Kaibab Band of
7 Paiute Indians and the Paiute Indian Tribe of Utah are also members of the Southern Paiute
8 Consortium (SPC). The Kaibab Band represents the SPC in matters pertaining to Glen Canyon
9 Dam and Colorado River management. Currently, the SPC is an active member of the AMWG
10 and the TWG, and the San Juan Southern Paiute Tribe is a member of the AMWG
11 (Reclamation 2012b).
12

13 The Canyons and the Colorado River have historic cultural significance as well as
14 contemporary interest to the Southern Paiute. Traditional narratives of Paiute origin vary from
15 band to band, but share a general central theme: “Southern Paiutes were the first inhabitants of
16 this region and are responsible for protecting and managing this land along with the water and all
17 that is upon and within it” (Bulleets et al. 2012).
18

19 The Southern Paiute maintain that when an undertaking is to occur in their traditional
20 homeland, it is their divine right to understand that action and the impacts that could occur from
21 that action (Stoffle et al. 1997). This is the reason the Kaibab Band of Paiute Indians and the
22 Paiute Indian Tribe of Utah formed the SPC in 1993 and participate in the management of lands
23 throughout the Colorado River drainage, through improved government-to-government
24 interaction in the GCDAMP. The consortium participates in and conducts its own assessments of
25 potential environmental impacts on ethnobotanical, geological, biological, and cultural resources,
26 the results of which are provided in technical reports (Bulleets et al. 2012).
27

28 According to traditional Southern Paiute values, all plants, animals, and natural elements
29 within that land should be respected and protected. The Southern Paiute have identified the
30 Colorado River as one of their most powerful natural resources and consider the Colorado River
31 corridor, as well as all natural and cultural resources within the corridor, as culturally significant
32 features (Stoffle et al. 1995). The Southern Paiute have identified numerous archaeological sites,
33 rock art sites, animal resources, ethnobotanical resources, traditional natural resources (soil,
34 water, rocks, and minerals), and traditional and contemporary use areas within the Colorado
35 River corridor that require monitoring and protection (Stoffle et al. 1994). Resources of
36 importance continue to be monitored by the SPC on a rotating basis (Austin et al. 1999;
37 Drye et al. 2000, 2001, 2002, 2006; Bulleets et al. 2003, 2004, 2008, 2010, 2011, 2012;
38 Snow et al. 2007).
39

40
41 **3.9.4 Hopi**
42

43 The following section was provided by a representative of the Hopi Tribe (Yeatts 2013).
44

45 Hopi culture begins with the emergence of people into the present world from the
46 *Sipapuni*, a spring located in the bottom of the Grand Canyon. After emergence, the ancestral

1 Hopi people (*Hisatsinom*) migrated in all directions around what is now the southwestern
2 United States. During the migration period, the Hopi Clans formed and ultimately came together
3 at the center of their universe: the Hopi Mesas. For many of the clans, the Canyons served as a
4 home during a portion of their travels.
5

6 The Hopi ancestors have been in the Grand Canyon region for more than a thousand
7 years. Their presence in the Canyons (*Öngtupqa*) is well documented in the archaeological
8 record. These ancestral archaeological sites are considered the footprints left by the *Hisatsinom*
9 as tangible markers of their covenant with the caretaker of the earth, *Masaw*, and as a cultural
10 claim to the land. At least 180 archaeological sites in the Colorado River corridor and in the
11 Canyons are considered by the Hopi Tribe to be ancestral homesites.
12

13 Evidence shows that sustained use of the Canyons by the *Hisatsinom* began around
14 A.D. 700–800. Use increased through time with numerous small pueblo sites dotting most of the
15 arable land in the canyon bottom by A.D. 1000. Both the northern and southern rims of the
16 Canyons were similarly occupied during this time period, and a trade network extended out in all
17 directions, linking the habitants of the Canyons to the broader region. Associated with some of
18 these pueblos were *kivas*, ceremonial structures found in every modern Hopi village and the
19 focus for religious activities. Just as modern Hopi villages have shrines associated with them, so
20 do these prehistoric counterparts. While people may no longer regularly deposit offerings at
21 these shrines, they are still considered active and sacred locations. Similarly, the sites are not
22 considered to be “abandoned” but are still viewed as serving as the homes of those who have
23 passed on. Proper respect for and treatment of the dead are extremely important values in Hopi
24 culture, and protection of their resting places is paramount. The Hopi people have a spiritual
25 obligation to serve as stewards of this land and, over the years, have developed a monitoring
26 program that evaluates Hopi values for the health on *Öngtupqa* (the Canyons) through time
27 (Yeatts and Husinga 2012). The Hopi are concerned with the erosion caused by the operation of
28 Glen Canyon Dam and the effect recreation has on places of cultural importance (Yeatts and
29 Husinga 2012).
30
31

32 **3.9.5 Navajo Nation**

33

34 For the Navajo Nation, or *Diné*, the canyons downstream from Glen Canyon Dam are
35 culturally and historically significant. The Colorado River and Little Colorado River are seen as
36 deities, and their confluence is associated with Changing Woman, the most important Navajo
37 traditional deity. Navajo lore includes an account of how *Haashch'ééh*, or “Humpback God,”
38 created the Grand Canyon by dragging his cane from east to west, creating a great chasm to drain
39 a flooded world (Two Bears 2012; Roberts et al. 1995). Glen Canyon, Marble Canyon, Grand
40 Canyon, and Little Colorado Canyon are home to many Navajo deities. Oral traditions recount
41 how these deities bestowed important ceremonial knowledge and taught the people how to use
42 the resources found throughout the landscape (Two Bears 2012).
43

44 Ethnohistoric accounts, as well as archaeological and linguistic evidence, suggest that the
45 Apacheans (Athabaskan-speaking ancestors of the Navajos and Apaches) entered the
46 North American Southwest sometime between A.D. 1000 and the 1600s. During this time, the

1 Apacheans traded and intermarried with neighboring groups, resulting in the traditional Navajo
2 culture of today (Brugge 1983; Brown 1991). According to traditional Navajo narratives, they
3 have always lived “among the four sacred mountains,” having emerged from the four
4 underworlds into this world at Mount Blanca (Two Bears 2012). By the mid-1800s, the Navajo
5 were fully utilizing resources in and around the Canyons for farming, livestock grazing, plant
6 gathering, hunting, and religious purposes (Navajo Nation 1962, undated). The Canyons also
7 served as a place of refuge from Mexican slave raiders, other Indian Tribes, and the U.S. Army.
8 During the 1860s, when Navajos were conquered by the U.S. Army and interned at Fort Sumner,
9 New Mexico, many Navajos escaped to the Canyons and lived there for many years. The
10 Canyons continued to provide protection to the Navajo and their herds of sheep, goats, and
11 horses during the federally imposed livestock reduction program of the 1930s and 1940s. Rivers,
12 springs, and seeps in the Canyons have provided water to people and livestock for generations.
13 Sites and remains of historic Navajo dwellings and sweat lodges in the canyons retain
14 importance for the Navajo (Roberts et al. 1995).

15

16 Both the Colorado River and the Little Colorado River protect and give life to the
17 Navajo. Offerings seeking the rivers’ protection continue to be made to the Colorado River.
18 Floodplains have provided arable land for corn fields, and the higher terraces have provided
19 habitat for wild game such as deer and bighorn sheep, as well as important food, medicinal, and
20 ceremonially important plants, which continue to be used today (Roberts et al. 1995).

21

22 Many mineral sources of cultural importance to the Navajo are found in the Grand
23 Canyon, including salt, red ochre, and quartz crystals. The salt source within the Grand Canyon
24 is personified as Salt Woman. A journey to Salt Woman consisted of following the Salt Trail
25 down the walls of and into the Grand Canyon, stopping periodically to make offerings and
26 perform rituals. To enter the Canyon, an individual had to be prepared mentally, physically, and
27 spiritually, and enter the Canyon in good faith, as it was the final resting for the spirits of their
28 ancestors (Roberts et al. 1995).

29

30 Many of the Canyon’s trails and river crossings retain important cultural meanings both
31 ritually and historically. The stories associated with the trails keep alive traditions of Navajo
32 history. The trails led to refuge, hunting, gathering, and trade with neighboring Tribes
33 (Roberts et al. 1995; Linford 2000).

34

35 Recently the Navajo have participated as a Cooperating Agency in the development of
36 NEPA documents concerned with environmental impacts on canyon resources downstream of
37 Glen Canyon Dam. The Navajo participated in in-depth cultural studies, which have identified
38 important archaeological, geological, botanical, and biological resources and TCPs within the
39 Colorado River corridor, and have provided monitoring and mitigation recommendations for
40 culturally important resources that are affiliated with the Navajo Nation. Important cultural
41 places include trails, subsistence areas, migration places, spiritual landscapes, and archaeological
42 sites that lie within and adjacent to GCNRA and GCNP (Thomas 1993; Roberts et al. 1995; Neal
43 and Gilpin 2000; NPS 2005a). Currently, the Navajo are active members of the AMWG and the
44 TWG (Reclamation 2012b).

45

46

1 **3.9.6 Zuni**
2

3 The following section was provided by the Zuni Cultural Resource Advisory Team in
4 association with the Zuni Cultural Resource Enterprise.
5

6 The Grand Canyon and the Colorado River have been sacred to the Zuni people since
7 their emergence onto the surface of the Earth. According to the traditional narratives that
8 describe the emergence of the Zuni people (*A:shiwí*) from Earth Mother's fourth womb, sacred
9 items that identify the Zuni people, the *Etdo:we* (fetish bundles), were the first to emerge; the
10 people then came out into the sunlight world at a location in the bottom of the Grand Canyon
11 near present-day Ribbon Falls. The creation narratives also describe the Zunis' subsequent
12 search for the center of the world, *ldiwan'a* (the Middle Place). During this search, the people
13 moved up the Colorado River and then up the Little Colorado River, periodically stopping and
14 settling at locations along these rivers. At the junction of the Little Colorado and the Zuni Rivers,
15 many of the supernatural beings, or Koko, came into existence. After a long search, the Zunis
16 located the middle of the world and settled there. The Middle Place is located in today's village
17 of Zuni.
18

19 The Pueblo of Zuni, the *A:shiwí*, continue to maintain very strong cultural and spiritual
20 ties to the Grand Canyon, Colorado River, and the Little Colorado River because of their origin
21 and migration narratives.
22

23 The Zuni River, Zuni Heaven (*Ko'lu:wa/a:wa*), the Little Colorado River, the Colorado
24 River, and the Grand Canyon have been important to Zuni culture and religion for many
25 centuries, if not a thousand years. Zuni religious beliefs, narratives, ceremonies, and prayers are
26 intrinsically tied to the entire ecosystem of the Grand Canyon, including the Zunis' familial
27 relationship with birds, animals, soils, rocks, vegetation, and water. The Grand Canyon is very
28 sacred, and the Zuni people place prayers and offerings in the Zuni River every morning and
29 evening which are then spiritually sent to the Grand Canyon via the Zuni River's confluence with
30 the Little Colorado River, and the Little Colorado River's confluence with the Colorado River in
31 Grand Canyon. The Zuni people are concerned with activities that may affect the resources in
32 this sacred place. Similarly, the Zuni people are concerned about activities that take place within
33 the Grand Canyon that may have an impact on Zuni.
34

35 The Canyons have significant religious and cultural importance to the Zuni. Zuni pray not
36 only for their own lands but for all people and all lands. To successfully carry out the prayers,
37 offerings, and ceremonies necessary to ensure rainfall for crops and a balanced universe, Zunis
38 must collect samples of water, plants, soil, rocks, and other materials from various locations.
39 Each part of the Zuni universe is interconnected. Plants, animals, and colors are associated with
40 the various cardinal directions. Minerals, clay, rocks, plants, and water are used in prayers.
41 Prayers are accompanied by offerings of prayer sticks. The entire environment at the bottom of
42 the Grand Canyon is sacred to the Zuni. The animals, the birds, insects, rocks, sand, minerals,
43 plants, and water in the Grand Canyon all have special meaning to the Zuni people.
44

45 For the Zuni, traditional cultural places encompass a wide variety of cultural sites
46 including, but not limited to, ancestral habitation sites; culturally significant

1 archaeological/historic features; pictographs and petroglyph sites; collection areas for plants,
2 water, and minerals; natural landmarks; prominent topographic features (e.g., mountains, buttes,
3 and mesas); shrines; sacred sites; and pilgrimage trails and routes. All archaeological sites,
4 including, but not restricted to, pictographs, petroglyphs, habitation areas, artifact scatters,
5 special use areas, and other archaeological manifestations, are considered ancestral sites which
6 imbue great cultural and religious significance to the Zuni people. For Zuni, these archaeological
7 sites have never been abandoned but continue to maintain life and spiritual forces significant to
8 the Zuni people. These archaeological sites are interconnected to one another by trails, and these
9 trails connect the sites to the Zuni Pueblo. Trails often lead to shrines and offering places.
10 Religious shrines are used by the Zuni to mark their land claim boundary, and these shrines
11 today are considered sacred. Shrines and other sacred cultural markers act in Zuni culture as
12 maps, charts, and other documents do in literate societies (Pandey 1995). The distribution of
13 shrines on the landscape act as cognitive maps for the Zuni when visiting these places and play a
14 significant role in reaffirming their cultural tradition and beliefs. Sacred shrines and offering
15 places were used by the Zuni ancestors, the *Che:be:ya:nule:kwe* and the *Enoh:de:kwe*. Sacred
16 shrines and offering places are often related to archaeological sites and are of great cultural and
17 religious significance. These shrines and offering places are also imbued with life and spiritual
18 forces. Shrines hold great significance to the Zuni and are considered sacred.

19
20 Shrines are also established at other places of significance within the Zuni cultural
21 landscape. The Zuni people preserve and maintain these “markers,” or locations, by making
22 regular visits or pilgrimages to deposit offerings and to ask blessings upon the land. Their
23 location is central to the purpose of the shrines. Thus, to disturb or move the shrines would be
24 incompatible with the essence of their location with respect to the areas and the people they
25 protect. Second, these locations have religious significance to the Zuni people, whether or not
26 they appear to have been used recently. Once established, they continue to provide their
27 protection in perpetuity.

28
29 The Zunis have many named places across their cultural landscapes that are
30 interconnected by a series of trails. Trails are important because they maintain strong and
31 continuous connections between the heart of the Pueblo of Zuni and many culturally important
32 distant places on the Zuni landscape. Trails are blessed before their use, and once blessed, they
33 are blessed in perpetuity. For the Zuni, there are many prayers and offerings that are required to
34 be made prior to a trip and during a trip, along the trail to the place of emergence and the
35 Grand Canyon. Prayers and offerings are made at springs and shrines along the trail. The trail,
36 the springs, and the shrine area are all sacred. The trail from Zuni to the Grand Canyon thus has a
37 continuously important religious meaning to the Zuni people. It is sacred and will also be used in
38 the afterlife. Once a trail is blessed, it remains blessed permanently. The Zuni people have
39 important concerns regarding the ancient Zuni trail from their village to the bottom of the
40 Grand Canyon.

41
42 The Pueblo of Zuni participated in the development of the 1995 EIS (Reclamation 1995)
43 as a Cooperating Agency and a PA signatory. Currently, the Pueblo of Zuni has active
44 representation on the AMWG and the TWG. The Zuni religious leaders, on behalf of the Pueblo
45 of Zuni, have developed a monitoring program to identify impacts on important Zuni cultural
46 resources in the Colorado River corridor resulting from the operation of Glen Canyon Dam.

1 Erosion and visitor impacts (i.e., trailing, litter, vandalism, and unauthorized artifact collection or
2 movement) have been identified as sources of impacts on archaeological sites and areas of
3 cultural importance (Dongoske 2011a). The results of monitoring are presented directly to
4 Reclamation and NPS.

5
6 On September 21, 2010, the Zuni Tribal Council passed resolution M70-2010-C086
7 which stated that the Zuni Tribe of the Zuni Indian Reservation "... asserts that the Grand
8 Canyon, from rim-to-rim, and all specific places located therein including the confluence of the
9 Colorado and Little Colorado Rivers, topographic and geologic features, springs, archaeological
10 sites, mineral and plant collection areas, and any other places it so identifies as historically,
11 culturally, or spiritually important to the Zuni Tribe within the Grand Canyon must, as a matter
12 of the United States government's trust responsibility toward the Zuni Tribe, be assumed by all
13 federal agencies to be eligible for the National Register of Historic Places and insists that all
14 agencies of the United States Department of the Interior (a) accept and respect the above
15 assertion with reference to any topographic or geologic feature, water body, or other place
16 identified by the Zuni Tribe as historically, culturally, or spiritually important within the Grand
17 Canyon; (b) respect Zuni tribal interests in and values ascribed by the Zuni Tribe and tribal
18 members to such places; and (c) accept and respect that the continued mechanical removal of
19 rainbow and brown trout at the confluence of the Colorado and Little Colorado Rivers is
20 considered an adverse effect on a traditional cultural property that is eligible for listing on the
21 National Register of Historic Places."

22
23 Appended to the Zuni Tribal Council Resolution was a Position Statement by the Zuni
24 religious leaders. The Position Statement asserted that the *Newe:kwe*, *Makeyana:kwe*,
25 *Uhuhu:kwe*, *Chikk'yali:kwe*, *Shuma:kwe*, *Halo:kwe*, *Sahniyakya*, *Shiwana:kwe*, Zuni Rain
26 Priests, Zuni Kiva Groups, and other associated religious societies demonstrate their passionate
27 support for the Pueblo of Zuni's cultural and religious objections (to mechanical removal of
28 rainbow and brown trout), reflected in a letter from Zuni Governor Cooyate to Mr. Larry
29 Walkoviak, Regional Director, Bureau of Reclamation, dated June 30, 2010, on the past and
30 proposed future mechanical removal management activities that consist of electroshocking and
31 destroying thousands of rainbow trout and brown trout at the confluence of the Little Colorado
32 River and Colorado River in Grand Canyon. It is the Zuni religious leaders' position that all
33 animals, including all aquatic life (e.g., native and nonnative fishes, insects, amphibians, snakes,
34 and beavers), birds, plants, rocks, sand, minerals, and the water in the Grand Canyon are sacred,
35 have special meaning, and a unique familial relationship to the Zuni people. The entire
36 environment at the bottom of the Grand Canyon is sacred to the Zuni people and the Grand
37 Canyon, including the confluence of the Little Colorado River and Colorado River, which are
38 integrally connected to Zuni religious beliefs, ceremonies, and prayers.

39
40 The Zuni annual ceremonial activities carried out at Zuni are performed for the specific
41 purpose to ensure adequate rainfall and prosperity for all life in the universe. The individual
42 Zunis that are part of these respective Religious Societies pray, fast, and perform religious
43 ceremonies not only for Zuni lands, but for all people and all lands. The ceremonies are
44 performed as part of maintaining a balance with all parts of this interconnected universe. As a
45 direct consequence of maintaining this balance and interconnectedness with the universe, the
46 Zuni religious leaders believe that the past and proposed future mechanical removal activities

1 created, and will continue to create, a counter-productive energy to the Zuni respective
2 ceremonial efforts to ensure rainfall, prosperity for all life, and to maintain a harmonious balance
3 among the Zuni people. The Zuni religious leaders expressed that they were especially concerned
4 that the continuation of the mechanical removal activities proposed for the confluence of the
5 Little Colorado and Colorado Rivers within Grand Canyon magnifies the negative effects of this
6 action for the Zuni people and all life. The Grand Canyon is very sacred, and the Zuni people are
7 concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni
8 people are concerned about activities that take place within the Grand Canyon that may have an
9 impact on the Zuni.

10
11 In summary, the Zuni River, Zuni Heaven (*Ko'fu:wa/a:wa*), the Little Colorado River, the
12 Colorado River, and the Canyons have been important to Zuni culture and religion for many
13 centuries. Zuni religious beliefs, narratives, ceremonies, and prayers are intrinsically tied to the
14 entire ecosystem of the Canyons, including the Zuni's familial relationship with birds, animals,
15 soils, rocks, vegetation, and water. The Canyons are very sacred, and the Zuni people are
16 concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni
17 people are concerned about activities that take place within the Canyons that may have an impact
18 on the Zuni.

21 **3.9.7 Fort Mojave Indian Tribe**

22
23 The *Pipa Aha Macav*, or “people by the River” (Fort Mojave 2012), are the northernmost
24 of the Yuman-speaking Tribes that established themselves along the banks of the Colorado River
25 well downstream from the Canyons. Traditionally, they lived in sprawling settlements adjacent
26 to and above the Colorado River floodplain, moving to the floodplain in the spring after seasonal
27 floods receded. Taking advantage of fresh moist silt deposited by river flooding, they planted and
28 harvested corn, beans, and squash, but also ranged widely, hunting, fishing, gathering mesquite,
29 and trading. They established the Mojave Trail and participated in a trading network that
30 stretched from the Pacific Coast to the Pueblos of the Southwest (Stewart 1983). Although they
31 ranged widely, their cultural center remained the river, which was created by *Mutavilya* along
32 with all plants and animals, which were drawn from the water (Fort Mojave 2012; Otero 2012).
33 Like their upstream neighbors, the Tribe views the river as a living being to which they are
34 connected. In the words of one Tribal member, “The river is the basis of who we are”
35 (Otero 2012). In the Mojave worldview, members of the Tribe are related to the natural world by
36 family ties and have stewardship responsibilities for its plants and animals. For the Mojave, some
37 trails have spiritual as well as temporal significance. The Salt Song Trail, an important ritual trail
38 tied to the afterlife, includes portions of the Grand Canyon.

39
40 The construction of dams along the Colorado River fundamentally changed the Mojave
41 lifeway. No longer could they make use of the river's annual floods to refresh their fields, but
42 even as they have adapted to changing circumstances, the river and their relationship to the
43 natural world based on spiritual ties have remained. The Mojave continue to be concerned about
44 the declining numbers of plants and animals in their homeland and the increase in nonnative
45 species. Created from the water, the natural world is affected by the way the river flows. Living

1 downstream from the project area, they are concerned with the effects of dam operation on water
2 quality and pollution (Otero 2012).

3.9.8 Indian Trust Assets and Trust Responsibility

7 The DOI acknowledges its federal trust responsibility and the importance of Indian trust
8 assets within the proposed action area. The trust responsibility consists of the highest moral
9 obligations that the United States must meet to ensure the protection of Tribal and individual
10 Indian lands, assets, resources, and treaty and similarly recognized rights. Secretaries of the
11 Interior have recognized the trust responsibility repeatedly and have strongly emphasized the
12 importance of honoring the United States' trust responsibility to federally recognized tribes and
13 individual Indian beneficiaries (Secretarial Order 3335; DOI 2014). Indian trust assets are legal
14 interests in property held in trust by the U.S. Government for Indian Tribes or individuals.
15 Examples of such resources are lands, minerals, or water rights.

17 The action area is bounded on the east by the Navajo Indian Reservation and on the south
18 by the Hualapai Indian Reservation. The DOI and Reclamation have ongoing consultation with
19 these Tribes regarding potential effects of the proposed action on their lands, resources, trust
20 assets, and reserved rights. High-flow releases will inundate shoreline areas historically affected
21 by seasonal floods, and analysis of effects on resources show that the proposed action is not
22 likely to impact Indian lands, minerals, or water rights.

3.10 RECREATION, VISITOR USE, AND EXPERIENCE

27 This section describes the recreational and visitor-experience attributes found in the
28 portions of GCNRA, GCNP, and LMNRA that are related to flows of the Colorado River.
29 Recreational use is an important issue because the GCPA mandates that Glen Canyon Dam be
30 operated in a manner that protects, mitigates adverse impacts to, and improves the values for
31 which GCNP and GCNRA were established including, but not limited to, natural and cultural
32 resources and visitor use. Most of the description provided here focuses on resources and
33 activities found in the Colorado River corridor from just below Glen Canyon Dam within
34 GCNRA to the western boundary of GCNP at RM 277. In addition, because of the potential for
35 the alternatives to differentially affect seasonal lake levels of both Lake Powell in GCNRA and
36 Lake Mead in LMNRA, this section will also provide information on visitor use of both lakes
37 and lake recreational facilities, principally boat launching facilities, that could be affected by the
38 alternatives being evaluated. Recreation economics are discussed in Section 3.14 of this DEIS.

3.10.1 Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area

44 The Glen Canyon reach of the Colorado River is an approximately 15-mi segment of the
45 river between Glen Canyon Dam and Lees Ferry. Recreational activities include trout fishing,

1 motor- and human-powered boating, commercial flat-water rafting, camping, photography,
2 hiking, interpretation of historic and cultural properties, and sight-seeing.

3
4 The Glen Canyon General Management Plan (GMP) (NPS 1979) established
5 management zones within the NRA. The majority of the land along the Glen Canyon reach is
6 located within the Natural Zone and included in the park's wilderness recommendation. The
7 river is managed to provide for recreation. Visitor services include facilities for camping and
8 interpretation of resources (such as the descending sheep panel). The Navajo Indian Reservation
9 extends along much of the east side of the river immediately adjacent to the GCNRA boundary.

10 11 12 **3.10.1.1 Recreational Fishery**

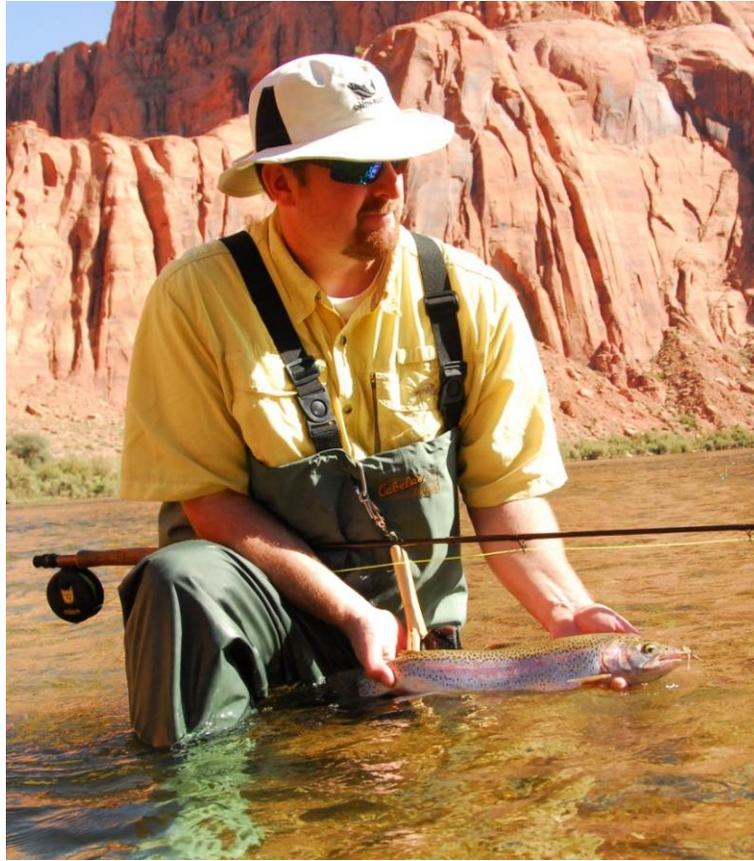
13 14 15 **Characteristics of the Glen Canyon Fishery**

16
17 The 15-mi Glen Canyon reach, upstream of Lees Ferry, supports a recreational fishery
18 that is an important recreational and economic resource based largely on nonnative rainbow trout
19 (Figure 3.10-1). Fish in all waters within GCNRA and GCNP are managed by the NPS, in
20 coordination with the AZGFD and the FWS. The condition of the recreational rainbow trout
21 fishery within GCNRA can be affected by the operations of Glen Canyon Dam, which is
22 operated by Reclamation. The Comprehensive Fisheries Management Plan (the Plan) for GCNP
23 and GCNRA (NPS 2013e) identified the goals for this fishery (Section 1.10.3).

24
25 Dam operations and fishery management may affect the size and quality of the rainbow
26 trout fishery and angler satisfaction. While there is a strong interest in maintaining the highly
27 valued trout fishery in the Glen Canyon reach, there also is concern about the migration of trout
28 to downstream areas, particularly near the confluence with the Little Colorado River, which is a
29 key concentration area for the humpback chub, a federally listed endangered species.

30
31 The recreational fishery has evolved over time. From 1964 until 1991, the rainbow trout
32 population of the Glen Canyon reach was sustained by annual stocking, but with the stabilization
33 of flows by dam operations, the trout population eventually became self-sustaining, although
34 stocking was continued through 1998. The trout population in the Glen Canyon reach has been
35 monitored on a regular basis by the AZGFD since 1991. Key population characteristics identified
36 from 1991 to 2009 inform an understanding of the relationships among dam operations, the trout
37 population, and native fish populations (Makinster et al. 2011).

38
39 The trout population and accompanying angler success rate in the Glen Canyon fishery
40 has been quite variable over the years in response to management actions, stocking, dam release
41 regimes, and food availability. The periods from 1972 to 1978 and 1978 to 1984 were known as
42 the fishery's Trophy Era and Quality Era, respectively (Reclamation 1995). It was during this
43 time that the Glen Canyon fishery achieved an international reputation as the fishery producing
44 10–20 lb trout, and bag limits of 10 fish weighing a total of 40 lb were not uncommon. From
45 1978 to 1984, the number of large fish being taken declined, but creel census reports still showed
46 an average weight of 2.79 lb for fish caught, and fish over 20 in. in length made up about 25% of



**FIGURE 3.10-1 Glen Canyon Reach Rainbow Trout
(Courtesy of George Andrejko, AZGFD)**

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5
6 the catch. From 1985 to 1988, fish longer than 20 in. made up less than 10% of the harvest and
7 the percentage of 15-in. fish harvested continued to increase (Reclamation 1995).

8
9 An estimated total of 10,908 anglers used the trout fishery in 2014, of which 6,739 were
10 boat anglers and 4,169 were walk-in anglers. Creel surveys conducted during 2014 found that
11 overall angler success remained high, with 95% and 64% of the anglers catching at least one fish
12 in the boat-fishing section upriver of Lees Ferry or walk-in section accessed at Lees Ferry,
13 respectively. Angler satisfaction on a scale of one to five remained high for both boaters and
14 walk-in anglers, averaging 4.55 and 4.28, respectively (Rogowski, Winters et al. 2015). The
15 angler catch rate generally correlates with the size of the fish population; Figure 3.10-2 shows
16 the angler catch rate from 1977 to 2014. Catch rates peaked in 1998 and increased sharply again
17 after 2010, with 2012–2014 having the highest catch rates on record for boat anglers. Catch
18 rates for boat anglers have been roughly twice the rates of walk-in anglers in recent years. This
19 has been attributed to the ability of boat anglers to access preferred trout habitat; walk-in
20 angling catch rates are better correlated to those from electrofishing surveys (Rogowski,
21 Winters et al. 2015). Electrofishing data from 1991 to 2014 show that there has been a long-term
22 trend of decreasing fish size. In the 2014 electrofishing survey conducted in the Lees Ferry reach
23 in spring, summer, and fall months, 17% of rainbow trout collected were less than 152 mm

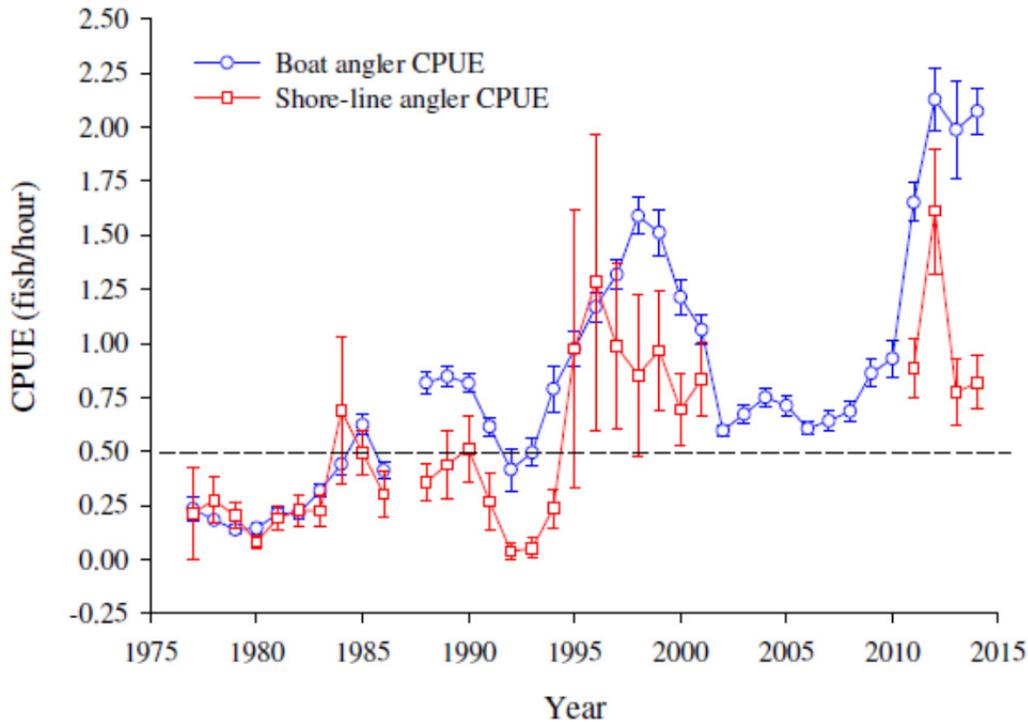


FIGURE 3.10-2 Mean Rainbow Trout Catch Per Unit Effort (CPUE, fish caught per hour) of Both Boat Anglers (blue) and Shore-Line Anglers (red) from Creel Surveys at Lees Ferry (Error bars represent 95% confidence intervals. The dashed line indicates the trigger point [0.5 fish/hour] for potential restocking of rainbow trout) (Source: Rogowski, Winters et al. 2015)

(6 in.) in length, 58% were in the 152–305 mm (6–12 in.) range, 24% were in the 306–405 mm (12–16 in.) range, and only about 1% were in the >405 mm (>16 in.) range (Rogowski, Winters et al. 2015).

Levels of Recreational Fishing Use

Fishing occurs year-round in the Glen Canyon reach, with the months of April and May being the peak months; however, substantial fishing use occurs from March through October in most years (Figure 3.10-3). Most fishing in the Glen Canyon reach is done from boats or is facilitated by boating access to gravel bars and riffles in the river upstream from the NPS Lees Ferry launching facility (Anderson, M. 2012). Fly fishermen fish both from boats and by wading bars, riffles, and along the shore, depending on river flow levels; spin fishermen more typically fish from boats. The availability of gravel bars for wading depends on river flow, with most bars being inundated at 15,000–16,000 cfs (Lovett 2013). There also is significant fishing use by walk-in anglers along the approximately 1.2 mi of shoreline between the Paria River confluence with the Colorado and just upstream of the launch facility. A significant number of anglers also access the Colorado River below the Paria River confluence on Paria Beach, further downriver via a system of trails and across the river on Navajo Nation land. Power boaters can access

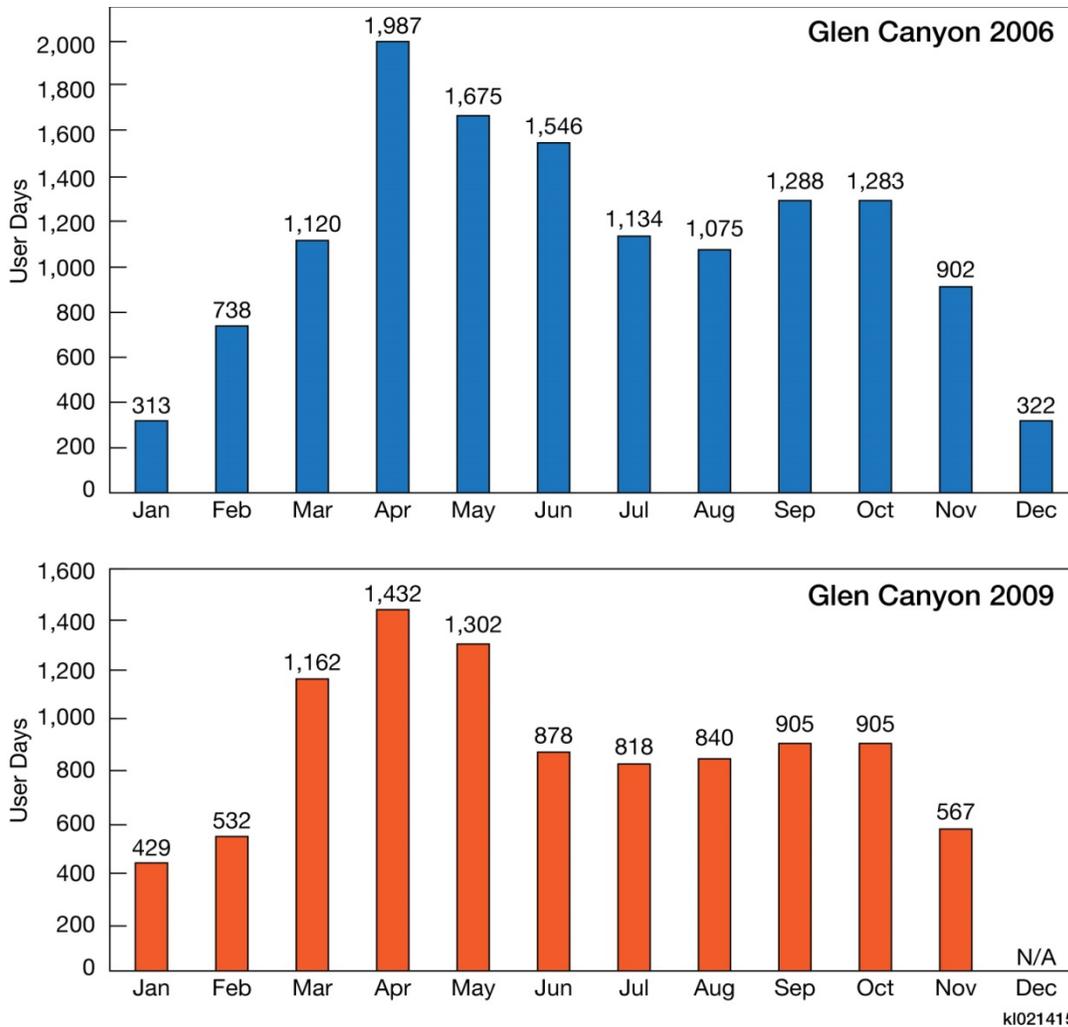


FIGURE 3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 (top) and 2009 (bottom) (User days for December 2009 were unavailable.) (Source: Reclamation 2011d)

almost the entire river upstream of the launch facility with only a small safety area below the dam being closed to access.

The AZGFD estimates that total fishing use in the Glen Canyon reach in 2011 was 87,000 hr (15,818 angler days)⁷ (Anderson, M. 2012). It is estimated that 70,000 hr (12,727 angler days) of angling effort were expended by boating anglers and 17,000 hr (3,091 angler days) were expended by walk-in anglers. Angler use days peaked at 52,000 in 1983

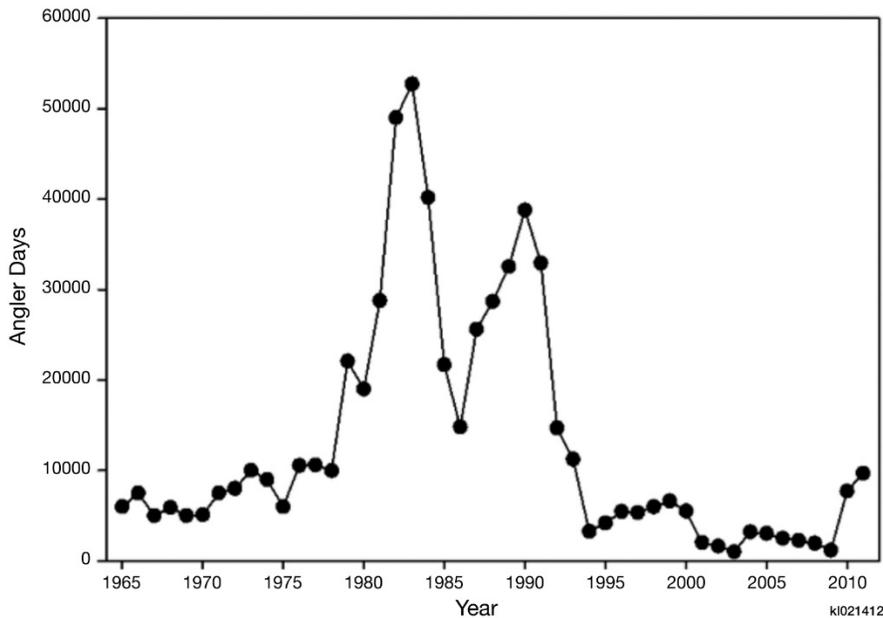
⁷ The methodology for calculating angler days depends on the assumed duration of an angler day. The computations here are based on the AZGFD statewide standard of 5.5 hr per trip, but it is understood that if other durations were used, the number of angler days would be somewhat different.

1 (Figure 3.10-4), but eventually dropped to an average of about 3,400 angler days per year from
2 the mid-1990s to 2009.

3
4 Based on AZGFD survey data, commercial guided fishing operations provided services
5 for about 50% of the boating-based fishing use in the Glen Canyon reach in 2011
6 (Anderson, M. 2012). In that year, there were five NPS-authorized commercial fishing guide
7 operations in the Glen Canyon area that provided boats and guide services in the Glen Canyon
8 reach (Blaise 2012). The AZGFD surveys did not identify any walk-in fishing use being
9 supported by commercial guides. NPS requires guide services to obtain a commercial use
10 authorization to operate in GCNRA; guide services are also required to report the number of
11 anglers they serve. The total reported number of commercial clients for the five commercial fish
12 guiding operations in the 4 years beginning in 2009 was 2,652, 2,665, 2,731, and 3,210,
13 respectively (Blaise 2012; Seay 2013). Historical levels as high 4,000 clients per year reported
14 for a single operator provides some perspective on the current level of commercial use
15 (Gunn 2012).

18 Important Attributes of Fishing in Glen Canyon, and Angler Satisfaction

19
20 The quality of the fishing experience in the Glen Canyon reach has been studied to help
21 understand what characteristics of fishing in the area are most important to participants. The
22 most comprehensive study to date was conducted by Bishop (Bishop et al. 1987), during the
23 period when dam operations resulted in large and rapid fluctuations in water flows, and shortly
24 thereafter, when the trout fishery was regularly producing large fish. Stewart et al. (2000), in
25
26



27
28 **FIGURE 3.10-4 Angler Days in the Glen Canyon Reach from 1965**
29 **through 2011 (Source: AZGFD 2012)**

1 another study, identified the flow regimes preferred by Glen Canyon anglers. Although the two
2 studies were completed under very different operating criteria, anglers in both studies identified a
3 marked preference for flows in the 8,000 to 15,000 cfs range. The Bishop et al. (1987) study
4 further identified a preference for steady, non-fluctuating flows. In the Stewart et al. (2000)
5 study, fluctuating flows were not identified as an issue, likely because fluctuations had been
6 reduced to MLFF levels by the time of the study. In both studies, anglers showed a clear dislike
7 of flows below 3,000 to 5,000 cfs.
8

9 Another attribute of fishing in the Glen Canyon reach affects fishermen who wade and
10 fish from the shore and gravel bars. High water levels, as well as rapid changes in water levels,
11 directly affect the safety of wading fishermen due to the potential for being swept away by the
12 river current. The 1995 Glen Canyon Dam EIS (Reclamation 1995) included a reference to three
13 drownings that were possibly related to river stage or stage change and noted that high flows
14 (30,000 cfs or more) reduced the safety of wading in the river. After the adoption of the MLFF
15 operating protocol in 1996, ramping rates were restricted, which has likely reduced the level of
16 this risk, as has the reduction of normal high flows to 25,000 cfs.
17
18

19 **3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon Reach**

20

21 The 15-mi Glen Canyon reach supports several recreational activities in addition to
22 fishing, including river floating, camping, and recreational boating. In calendar year 2012, the
23 NPS estimated that 210,627 recreation users visited the area (NPS 2014d). About 25% of the
24 annual visitors accessed the Glen Canyon reach via the pontoon-raft concession that departs from
25 near the dam and travels to Lees Ferry.
26

27 The NPS facilities at Lees Ferry consist of launch ramp, campground, restroom, and
28 interpretive facilities, as well as hiking trails. Upstream of the Lees Ferry launching facility,
29 there are six designated, boat-accessible-only, camping areas.
30

31 An NPS launching facility is the main access both for trips going downstream through the
32 Grand Canyon and for fishermen and other boaters heading upstream into the Glen Canyon
33 reach. Other facilities nearby interpret the human history and existing historic structures
34 associated with the historic Lees Ferry crossing. Aside from the courtesy dock located next to the
35 launch ramp, facilities in this area are not directly affected by river fluctuations.
36

37 Camping in the Glen Canyon reach is allowed in six designated areas. These areas are
38 located on sediment terraces and beaches. Figure 3.10-5 shows the general location of the six
39 designated campsite areas; Figure 3.10-6 illustrates the affected shoreline environment in the
40 GCNRA area.
41

42 Besides recreational power boating, the NPS authorizes one concessionaire, Colorado
43 River Discovery (CRD), to provide a variety of river services in the Glen Canyon reach. The
44 most popular of these is a half-day guided trip that originates at the dam; most CRD trips are
45 motorized pontoon rafts; however nonmotorized full-day trips are also offered.
46

1 The most popular trips are run twice a day
2 during the main part of the recreation season. The rafts
3 have a maximum capacity of 22 people (Figure 3.10-7).
4 At the end of the trip, passengers are transported by bus
5 from Lees Ferry back to Page. The passenger numbers
6 served by CRD are shown in Table 3.10-1. The trips
7 generally originate in Page, Arizona, at the company's
8 rafting headquarters. The company provides
9 transportation to the launch site, which involves
10 traveling through a 2-mi-long tunnel that provides
11 access to the river near the base of the dam. CRD also
12 offers a "backhaul" service that transports private
13 canoes/kayaks upstream from Lees Ferry into the Glen
14 Canyon reach.

16 HFEs create operational issues for the rafting
17 concessionaire including cessation of operations for a
18 period of days and the need to move mooring docks
19 and rafts or to relocate operations to the Lees Ferry
20 launch site, which is a less economically desirable
21 location.

23 Although the concessionaire does not operate
24 during an HFE, the departure/mooring docks for the
25 day-rafting operation are located just below the dam
26 and HFEs in excess of power-plant capacity of
27 31,500 cfs requires that the concessionaire's rafts either
28 be removed from the river or relocated because of
29 turbulence caused by the discharge from river bypass
30 tubes. The concessionaire also must remove boarding
31 steps that allow passengers to get from the dock to the
32 boats. With 21 boats, this is a major amount of work
33 that disrupts business operations.

35 During the 2012 HFE event, the concessionaire indicated that the business was disrupted
36 for 2 days before and after the HFE, as well as during the HFE.

38 In cases of extended high flows (such as 1983–1984), rafting operations have been
39 relocated to the Lees Ferry launch site where they continued limited and modified operations.
40 These operations require the rafts to travel upriver against heavy current with a reduced
41 passenger load. In this scenario, the rafts travel upriver through a portion of the canyon using an
42 outboard motor before floating back down to the starting point (Grim 2012). During high-flow
43 events (other than scheduled HFEs), docking at Lees Ferry is more difficult than normal because
44 the dock is actually in the river channel, as opposed to being out of the main current. Departing
45 from Lees Ferry rather than the dam keeps the business functional to some degree, but the
46 economics of this type of operation are unfavorable compared to normal operations.

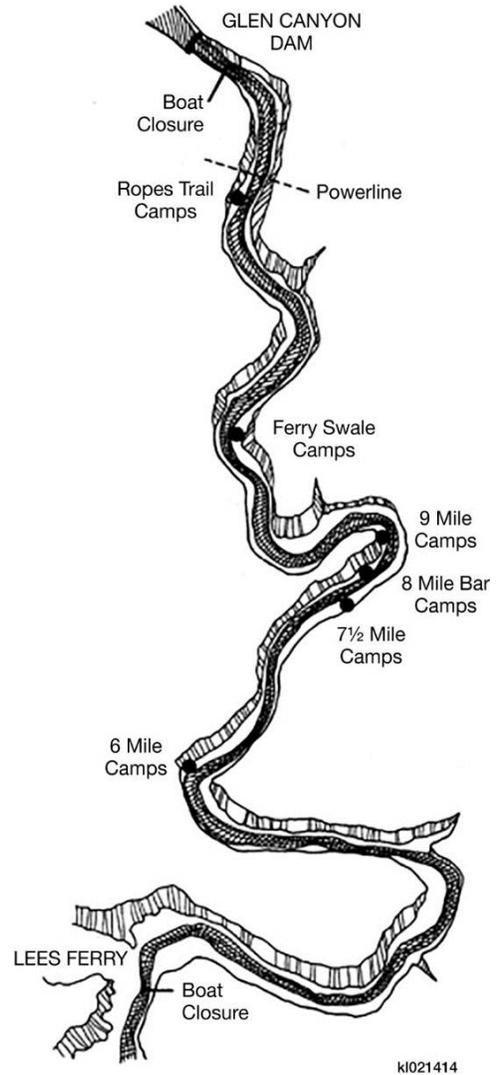


FIGURE 3.10-5 Designated Campsite Areas in the Glen Canyon Reach (GCNRA 2014)



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FIGURE 3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach Ferry Swale Campsite (courtesy of GCNRA)



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FIGURE 3.10-7 Pontoon Raft Operated by Colorado River Discovery

1
2

TABLE 3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–2013

Month	2009	2010	2011	2012	2013 ^a
January	0	0	0	0	0
February	159	8	19	48	100
March	2,211	2,131	1,922	2,163	2,416
April	5,256	4,599	4,533	4,801	3,914
May	6,346	6,629	6,831	7,438	6,684
June	9,333	9,905	9,444	10,372	8,880
July	9,256	9,887	9,389	9,515	8,661
August	7,866	7,367	7,050	7,773	6,479
September	5,415	6,287	6,001	6,300	5,245
October	3,825	3,824	3,978	4,363	1,311
November	735	687	458	535	562
December	0	0	0	0	8
Totals	50,402	51,324	49,625	53,308	44,260

^a The 2013 passenger counts were affected by the closure of AZ Highway 89 in February 2013.

Source: Blaise (2014).

3
4

River fluctuations were identified as an issue for both anglers and white-water boaters in previous studies (Bishop et al. 1987; Stewart et al. 2000). However, both studies found that daily river level fluctuations had no impact on the satisfaction level for day-rafting clients.

8

HFEs create steep banks in some portions of the river that make access from boats to the upper sediment terraces more difficult, as shown above in Figure 3.10-6 (Grim 2012; Hughes 2014a). Eventually most steep areas are eroded by use, restoring easy access to the terraces, but in some locations, the banks have been steepened to such a degree that visitor access is adversely affected. The six designated recreation sites located on these sediment terraces are shown above in Figure 3.10-5.

15

3.10.2 The Colorado River in Grand Canyon National Park

18

GCNP is a world-renowned recreational destination that was designated as a World Heritage Site in 1979. The 1,217,261-ac park contains 1,143,918 ac proposed for wilderness designation, including 10,919 ac of potential wilderness along the Colorado River corridor. Annual visitation to the park has exceeded 4 million visitors since 1992, and 4,564,840 visitors were recorded in 2013. Most visitors focus on the developed facilities on the South Rim of the canyon, where the majority of the visitor services, facilities and administrative offices are located.

26

While GCNP is a destination for millions of visitors, the focus of this DEIS is on the Colorado River corridor, which constitutes a small percentage of the acreage of the park and

27

28

1 small portions of both Glen Canyon and Lake Mead NRAs. The Colorado River Management
2 Plan (CRMP), completed in 2006 (NPS 2006b), set goals for managing visitor use and protecting
3 resources along the river corridor. The CRMP established a visitor capacity based on the number,
4 size, and distribution of campsites; natural and cultural resource conditions; and visitor
5 experience. The NPS established a capacity of 60 trips at one time; and is managed through daily
6 launch limits, group size, and trip length. The CRMP also established a 6.5-month no-motors
7 season to provide enhanced wilderness opportunities. The CRMP outlines a Research, Monitoring,
8 and Mitigation Program that manages resources in the river corridor within an adaptive
9 management framework (NPS 2006c).

10
11 A whitewater trip through all or part of the Grand Canyon is a rich and complex
12 recreational experience, valued for the sights and sounds of the canyon, the whitewater, and
13 superb opportunities for varied recreational experiences. Recreational river use in the Grand
14 Canyon expanded from 150 people per year in 1955 to 16,500 in 1972 and to the 2006 CRMP
15 levels of about 24,657 visitors per year.

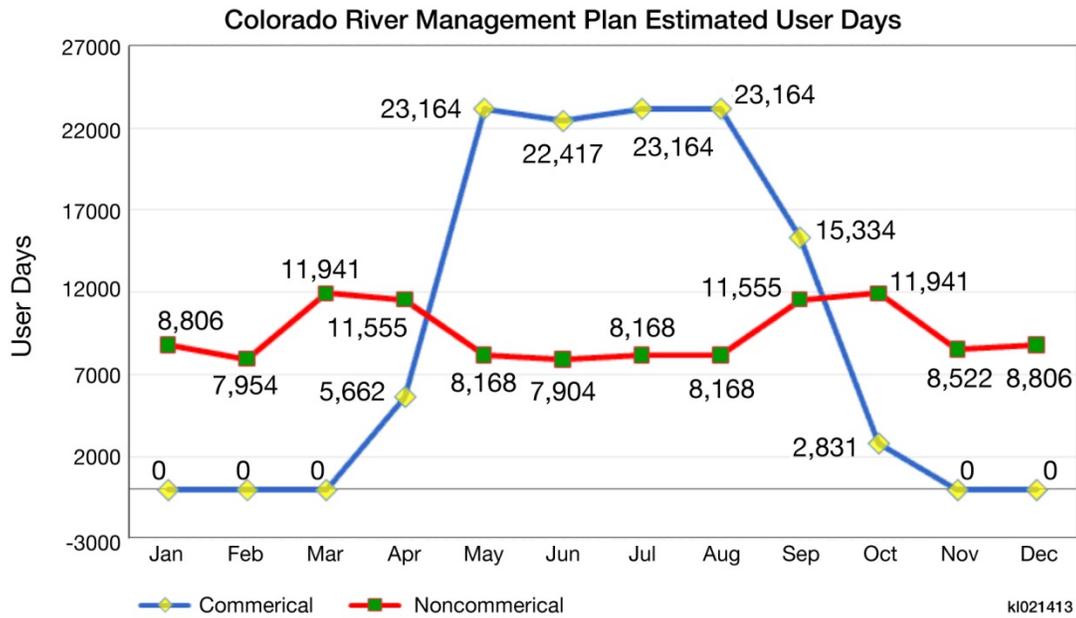
16
17 Visitor use is measured in user days (e.g., one person on the river for a day), and is
18 managed to offer a variety of trip types throughout the year. Trips are conducted using a variety
19 of types and sizes of boats and rafts; group sizes can range up to 32 people (including guides);
20 trip lengths range up to 25 days; trips can be run by commercial companies or by private
21 individuals; and there are various means of joining trips, including launching from Lees Ferry,
22 hiking into or out of the canyon to join or leave a trip at Phantom Ranch, and limited access by
23 vehicle and helicopter (commercial use only) to join trips in the western portion of Grand
24 Canyon.

25
26 Commercial river trips are offered from April through October and noncommercial trips
27 occur year round. Peak use occurs in May through September as shown in Figure 3.10-8.

28
29 Most Grand Canyon river trips begin at Lees Ferry (RM 0) and take out at Diamond
30 Creek (RM 226) or at Pearce Ferry (RM 280) in LMNRA. When Lake Mead water levels were
31 higher prior to the onset of drought in 2000, trips also regularly ended at South Cove (RM 295)
32 on Lake Mead. Prior to the drought, lake travel began at Separation Canyon, and many trips
33 either motored or were towed by jet boats that came upriver from Lake Mead to their take-out
34 points at Pearce Ferry or South Cove.

35
36 The Lower Gorge of the Grand Canyon is defined as the 51-mi section of river below
37 Diamond Creek (RM 226) to Pearce Ferry (RM 280). Recreational use of the Lower Gorge is
38 described in the CRMP and is managed by the NPS and the Hualapai Tribe, whose reservation is
39 on the south side of the river (located approximately between RM 164.5 and RM 273).

40
41 Types and levels of recreational use in the Lower Gorge vary greatly from those above
42 Diamond Creek, primarily due to road and boat access to the river by way of the Hualapai
43 Reservation at Diamond Creek and to the influence of Lake Mead. In addition to river trips that
44 launch from Lees Ferry and continue into the Lower Gorge, the NPS permits noncommercial



1

FIGURE 3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month
 (Source: Reclamation 2011b)

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(private) and educational trips launching from Diamond Creek. In addition, the Hualapai Tribe operates its own river program that provides commercial trips beginning at Diamond Creek and other sites on Tribal lands.

9

10

Most trips spend fewer than three nights total in the Lower Gorge, although it is possible to spend more if boaters are interested in lake travel or off-river hiking. Backcountry permits are required to camp off the river in GCNP, and Hualapai Tribal permits are required for launching and camping on the reservation.

14

15

Campsites in Grand Canyon National Park

17

18

River-accessed campsites within GCNP are a memorable aspect of any recreational experience along the river. The number of available campsites and the amount of campsite area at any particular time are affected by river flow (i.e., fewer campsites are available at higher flows, and vice versa). Because of their singular importance in supporting river use, there have been numerous campsite inventories over the years; NPS reported in the CRMP that there are over 200 regularly used camping beaches in the GCNP planning area. The number and usability of campsites vary from year to year based on several factors, including flow regimes; vegetation changes; erosion from tributary flooding, wind, or recreation use; or closure of sites to protect sensitive resources (NPS 2005a). An updated campsite inventory conducted by the NPS in 2011 identified and classified by capacity 235 campsites between Lees Ferry and Diamond Creek.

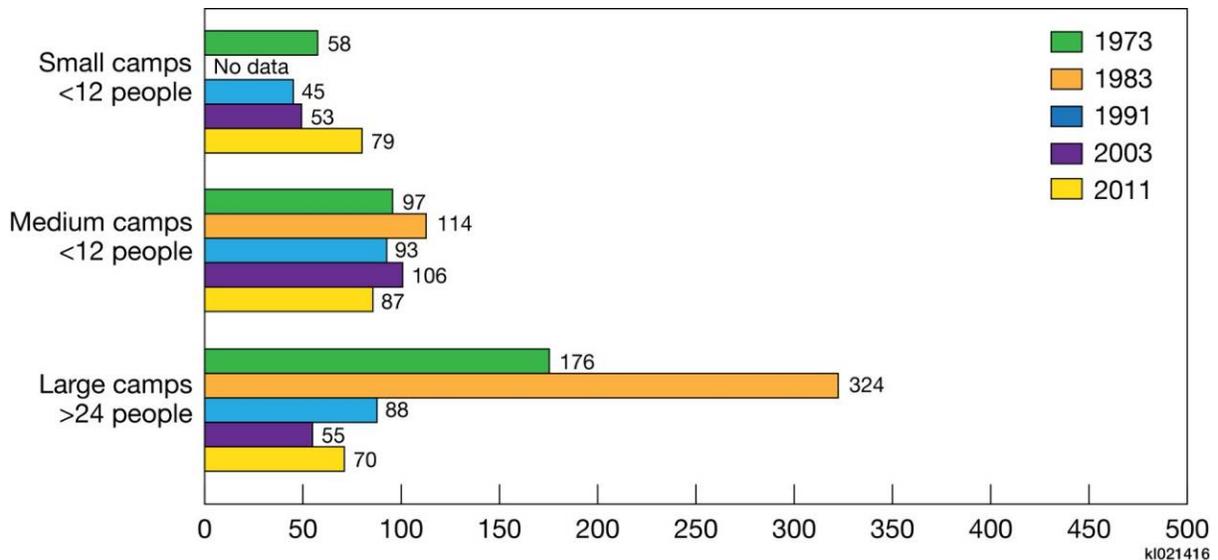
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1 Preferred beach characteristics for both camping and stops for lunch include a strong
 2 preference for shade, larger rather than smaller beaches, and the availability of hiking
 3 opportunities (Stewart et al. 2000). “Campable area” is the term used to describe the area of a
 4 beach where people set up camp, moor boats, cook, and sleep. The criteria used to define
 5 campable area include a smooth substrate, preferably sand, with no more than 8 degrees of slope,
 6 and with little or no vegetation (Kaplinski et al. 2010).

8 Campsites are further classified as being located in either critical or noncritical reaches of
 9 the river. A critical reach is any contiguous stretch of river in which the number of available
 10 campsites is limited because of geomorphic setting (e.g., narrowed canyon width), high demand
 11 for nearby attraction sites, or other logistical factors (e.g., exchange points). Noncritical reaches
 12 are those stretches in which campsites are relatively plentiful, resulting in little competition for
 13 most sites (Kearsley and Warren 1993).

15 Campsites vary in size and not all can accommodate the maximum group of 32 described
 16 in the CRMP. Researchers, using campsite inventories, have developed three general categories:
 17 small camps (1 to 12 people); medium camps (13 to 24 people); and large camps (25 or more
 18 people) (NPS 2005a). The results of five campsite inventories conducted between 1973 and 2011
 19 are shown in Figure 3.10-9.

21 The highest number of camps (particularly large camps) recorded was documented
 22 during the inventory conducted immediately following the 1983 flood. By contrast, the
 23 1991 inventory shows 75% fewer large camps than in 1983, while the 2003 inventory shows an
 24 even further reduction (NPS 2006b). Compared to 1973, there was about a third as many large
 25 camps and a third fewer total camps in 2003 (NPS 2005b). The loss of the large campsites is
 26 especially problematic, given the number of large commercial trips during the summer season.



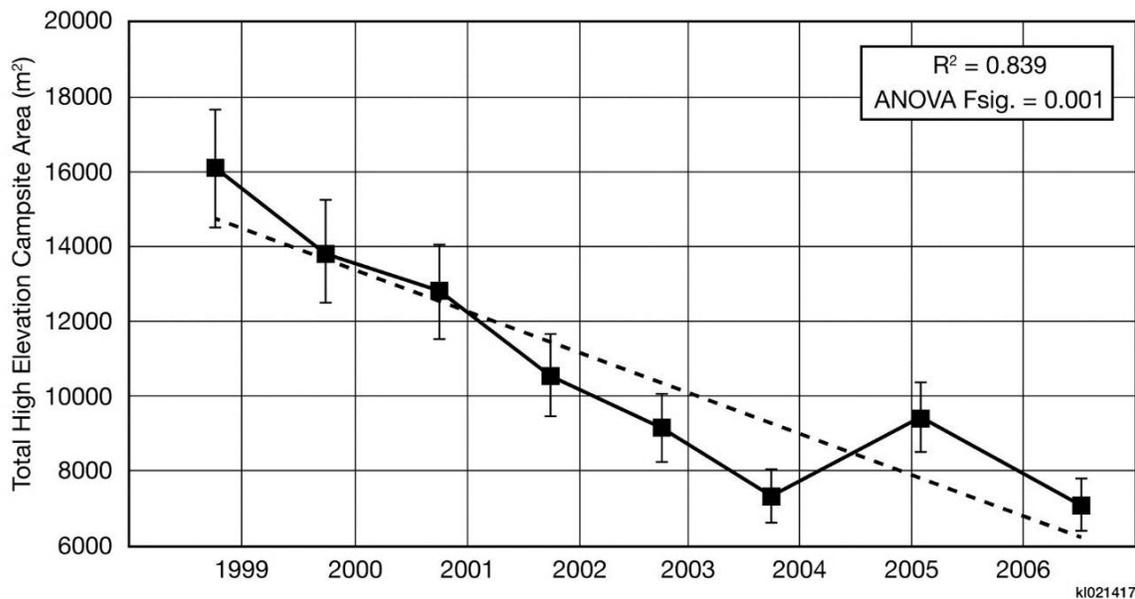
29
 30 **FIGURE 3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach of**
 31 **GCNP (Sources: NPS 2005a; Jalbert 2014)**

1 The loss increases the potential for groups to camp in close proximity to one another, especially
 2 in the critical reaches. This loss led the NPS to reduce group size as identified in the CRMP.
 3

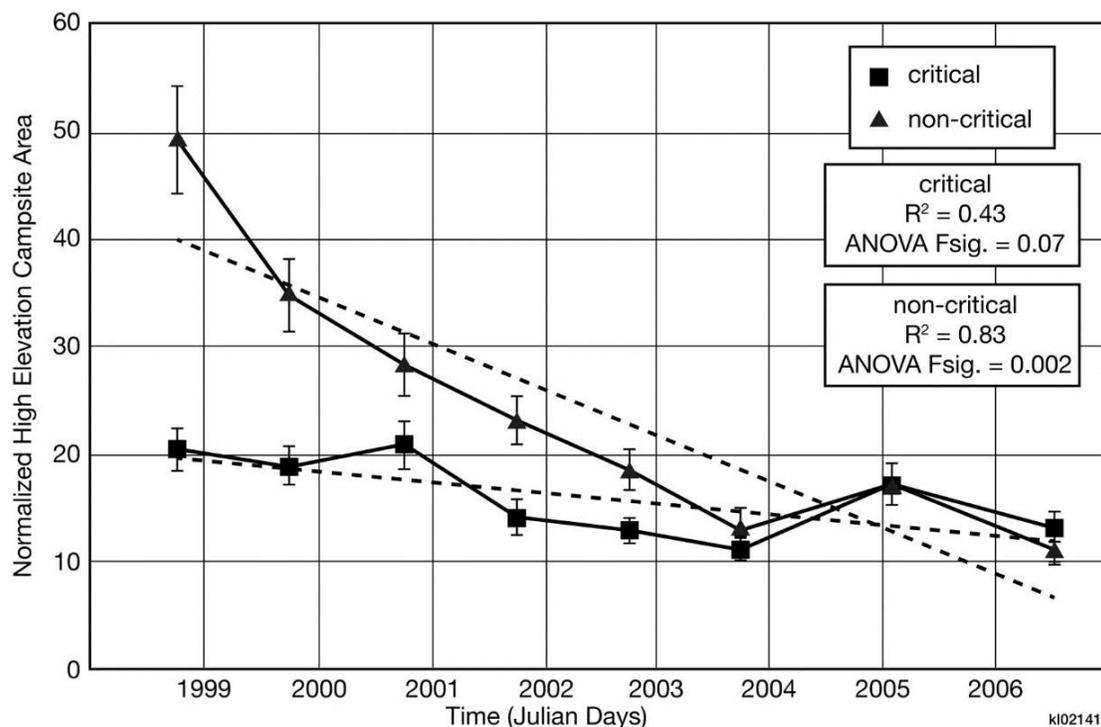
4 The most important finding regarding campsites in Grand Canyon is that they are
 5 becoming smaller and less abundant. A synthesis of geomorphic data on sandbars below Glen
 6 Canyon Dam reported a 25% reduction in the sandbar area within the 87-mi reach from Lees
 7 Ferry to Bright Angel Creek between 1984 and 2000 (Schmidt et al. 2004). A study completed in
 8 2010 summarizing detailed topographic campsite monitoring of a sample of 38 sites in GCNP
 9 showed that the total amount of high-elevation campsite area above the elevation of 25,000 cfs
 10 flow decreased 56% between 1998 and 2006. Figure 3.10-10 shows the described trend for high-
 11 elevation campsite area. The primary factors identified in campsite loss were riparian vegetation
 12 growth and sandbar erosion. These losses happened in spite of a temporary increase of 29% in
 13 campsite area between the inventories in 2003 and 2005 that was related to both the 2000
 14 summer low steady flow experiment and the 2004 HFE (Kaplinski et al. 2010). The diminishing
 15 availability of campable area, particularly in some of the narrower reaches of the river corridor,
 16 is an important issue for national park managers and recreational river runners.
 17

18 The 2010 Kaplinski et al. study agreed with the findings of Kearsley and Warren (1993)
 19 that campsite area in critical reaches decreased primarily due to erosion, and in noncritical
 20 reaches, due to increased vegetative cover. Figure 3.10-11 plots the loss of high-elevation
 21 campsite area in critical and non-critical reaches.
 22

23 Over the long term, eddy-sandbar size can only be increased if (1) adequate sediments are
 24 available for deposition, (2) high-flow deposition is substantial, (3) high flows occur frequently,
 25
 26



27
 28 **FIGURE 3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and**
 29 **2006 (with 10% uncertainty bands; the dashed line shows the linear regression fit)**
 30 **(Source: Kaplinski et al. 2010)**



1

FIGURE 3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between 1998 and 2006 (with 10% uncertainty bands; the dashed lines show the linear regression fit) (Source: Kaplinski et al. 2010)

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River Flow and Fluctuation

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and (4) erosion that occurs between high flows is less than the deposition. Thus, the net effect of high flows in building eddy sandbars results from the magnitude and the frequency of high flows and the deposition they cause. Erosion ensues rapidly after each high flow, and the rate of erosion declines thereafter but persists. The longer the time period between HFES, the more erosion occurs (Melis 2011).

High flows similar in magnitude to those that occurred during the HFES of 1996, 2004, 2008, 2012, 2013, and 2014 effectively mobilize accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild eddy sandbars in Marble and Grand Canyons. Grams et al. (2010) reported that more erosion occurs when total flow is large (excluding HFES). Fluctuating flows under normal dam operations between HFES can erode sandbars and campsites.

The effect of river flows on recreation in Grand Canyon has been the subject of studies on the Colorado River for many years that have utilized information from river guides and river trip participants to understand what attributes of river trips are important and how they can be affected by variable river flows (Bishop et al. 1987; Hall and Shelby 2000; Shelby et al. 1992; Stewart et al. 2000; Roberts and Bieri 2001; Ralston 2011). The operation of Glen Canyon Dam

1 commenced in 1963, and the flow regime of the river was first modified in 1991 to address
2 issues that were affecting downstream resources (Reclamation 1995). Principal among these
3 changes was a change in the maximum level of daily river fluctuations from 30,500 cfs to
4 5,000 cfs, 6,000 cfs, or 8,000 cfs, depending on the scheduled monthly release volumes.
5

6 Participants on Grand Canyon river trips have consistently identified several flow-related
7 attributes as being extremely important to their overall trip satisfaction; these include the
8 presence of large rapids, being the only camping group at a beach, and having large beaches for
9 camping (Bishop et al. 1987; Stewart et al. 2000). Large rapids are a function of higher flows.
10 Bishop et al. (1987) found a strong preference among boaters for flows in the range of 25,000–
11 35,000 cfs, a flow range that has been less common since 1996. Flows in this range provided the
12 further benefit that passengers were less likely to be required to walk around rapids. Conversely,
13 higher flows were identified as a potential contributor to crowding at campsites and attractions
14 (Bishop et al. 1987).
15

16 The Bishop study (Bishop et al. 1987) further evaluated whitewater boater's preferences
17 with respect to levels of daily flow fluctuations. The study, which was conducted at a time when
18 very large fluctuations were common, identified fluctuations in excess of 10,000 cfs as being
19 noticeable and perceived as less natural to canyon visitors. High fluctuations, ranging from 3,000
20 to 25,000 cfs/day, were also noted as contributing to issues related to selection of campsites, time
21 allowed at attractions, mooring and tending of boats, transiting major rapids, and trip scheduling.
22 Although such high levels of daily fluctuations are greater than under any LTEMP alternatives,
23 river guides in the Bishop study were also asked to evaluate fluctuation levels that happen to
24 overlap with the alternatives. River guides reported that tolerable fluctuations increased with
25 increasing average daily flow, as shown in Table 3.10-2 (adapted from Bishop et al. 1987), and
26 that the ability to run a whitewater raft trip was particularly sensitive to flow fluctuations when
27 daily flows were low. Based on interviews with guides, the authors concluded that the identified
28 "tolerable" fluctuation ranges were more of a "wish" in the eyes of the guides than specifically
29 "tolerable," as identified on survey forms, and noted that guides stated that predictability in
30 fluctuations is a key factor in coping with daily fluctuations (Bishop et al. 1987).
31

32 Shelby et al. (1992) documented that with daily fluctuations of 9,000–10,000 cfs,
33 boatmen reported problems with boats "left hanging" on beaches by receding water levels. By
34 the time of the Stewart et al. (2000) study, daily fluctuations had been reduced by the MLFF
35 operating regime (capped at 8,000 cfs). Stewart et al. (2000) indicated that "the negative effects
36 of fluctuating flows on recreational use were not substantial problems," but also recorded that
37 "user attitudes and preferences regarding constant flows" had not changed since the 1987 Bishop
38 study.
39

40 It is clear from numerous studies that river flow and management regimes affect
41 whitewater rafting experiences (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000;
42 Ralston 2011). There is general agreement that flows in the 20,000 to 25,000 cfs range are
43 considered to be near optimum for all types of whitewater trips (commercial oar and motor trips
44 and private trips); there is also general agreement that flows of less than about 10,000 cfs are
45 considered to be marginal, while flows of less than 5,000 cfs are considered to be highly
46 unsatisfactory (Bishop et al. 1987; Stewart et al. 2000).

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**TABLE 3.10-2 Tolerable Daily Flow
 Fluctuations Reported by Commercial and
 Private Trip Leaders**

River Flow (cfs)	Tolerable Within-Day Fluctuation (cfs) ^a
5,000–9,000	2,400–3,400
9,000–16,000	3,900–4,800
16,000–32,000	6,400–7,200
32,000 and up	7,900–9,800

^a Range of mean daily tolerable fluctuations reported by commercial motor guides, commercial oar guides, and private trip leaders who had experienced fluctuations of 15,000 cfs in Grand Canyon.

Source: Bishop et al. (1987).

Time Off of the River. A large array of attraction sites, short to long hikes, and campsites are parts of the experience of most river trips through GCNP. There are over 100 attraction sites available along the river that can be incorporated into a trip, depending on the time available. Most river trips are run on a planned schedule, but longer trips (in number of days) tend to have more flexibility than shorter trips (Roberts and Bieri 2001).

For a river trip of a given distance, river flow rate affects the time available for off-river activities. River flow affects boat speeds, even for motor trips, which affects distance traveled per unit of time. Roberts and Bieri (2001), in their study of the effects of the low steady summer flow experiment of 2000, documented that at a normal flow of 19,000 cfs, river trips spend approximately 7 hr “off river” engaged in activities such as hiking and visiting attraction sites, while during an 8,000-cfs low-flow study, groups spent only about 3.5 hr in these activities. Bishop et al. (1987) recorded that guides indicated that at around 30,000 cfs, additional attraction sites could be included into itineraries. Interestingly, Roberts and Bieri (2001) documented that although substantially less time was available for attraction stops at low flows, the average number of stops stayed near to the norm for average flows. The explanation for this appears to be that some attractions are simply “must see,” and a shorter amount of time was allotted for each attraction rather than dropping a site. It was also recorded that some sites become more preferred at lower flows because the activities at those sites require less time to complete. These observations confirmed findings regarding flow impacts on river trips of previous studies (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000).

Studies have also documented that river flows can affect the choice of campsites, how late campsites are reached, how early trips need to break camp, how much or little boatmen are required to row or run motors to keep a trip on schedule, and how many layover days can be taken. Bishop et al. (1987) and Stewart et al. (2000) speculated that the optimum flow level for a Colorado River trip is in the 20,000–25,000 cfs range because of the flexibility that flow offers in accommodating the various competing needs of these trips.

1 During low-flow periods, in addition to reducing the amount of time at attraction sites,
2 river guides may ask their group to break camp early or they may arrive at camp later in the day
3 than under normal flows. This reduces the amount of camp time, which can also reduce overall
4 trip satisfaction because of the reduced opportunity to explore the areas around camp, to
5 participate in camp activities, or to simply relax.
6

7 Having a wilderness experience is one of the top five attributes sought by whitewater
8 boaters (Bishop et al. 1987; Stewart et al. 2000). River flows can have effects on the wilderness
9 experience in at least two ways. The extent that flows limit or reduce the amount of time visitors
10 can spend enjoying the off-river activities affects this aspect of their wilderness experience. In
11 addition, low flows require more motor use during motor-powered river trips (Bishop et al. 1987;
12 Stewart et al. 2000) to maintain schedules. This introduces an additional noise component to the
13 boaters and to the surrounding environment that detracts from the wilderness experience.
14

15
16 **Whitewater Boating Experience.** One of the attributes desired by participants in river
17 trips is the opportunity to experience big rapids with large waves and a roller-coaster-type ride
18 (Bishop et al. 1987; Stewart et al. 2000). The condition of rapids is related to the flow, with low
19 levels tending to reduce the size of the rapids and the quality of the ride, while high flows tend to
20 wash out smaller rapids. The perception of the quality of rapids is important to an individual's
21 river experience; most related studies were conducted prior to implementation of MLFF and
22 generally identify flow levels of 20,000 to 25,000 cfs as being the optimum "ride" for most
23 participants (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000). Walking around rapids
24 has been identified as one of the attributes that negatively affects the perception of river trips
25 (Bishop et al. 1987; Stewart et al. 2000). Under reduced normal high-flow levels, having
26 participants walk around rapids now is more likely to be related to lower flows.
27

28
29 **Availability of Campsites.** Higher flows result in reduced campsite area, which can lead
30 to campsites being pushed into more sensitive riparian and old high-water zones. They can also
31 result in more competition for campsites, especially in the critical reaches. Reduced campsite
32 availability can further lead to camps being located more closely together, adversely affecting a
33 sense of solitude and the wilderness experience. In addition, higher flow fluctuations affect the
34 ability to both moor boats with less need to attend to them during the night and to access
35 campsites from the river level (Bishop et al. 1987). Current fluctuation levels under MLFF have
36 reduced but not eliminated this issue compared to previous operations (Stewart et al. 2000).
37

38 39 **Hualapai Tribe Recreation Program**

40
41 The Hualapai Tribe has implemented a comprehensive recreation services program
42 utilizing Tribal lands that border the Colorado River in the Grand Canyon to generate income for
43 the Tribe. The Tribe, through its Grand Canyon Resort Corporation, manages several businesses
44 that provide recreation services, including a river rafting company. Hualapai River Runners
45 (HRRs) is the only Tribally owned and operated river rafting company on the river. HRR offers
46 commercial motorized day trips from the Diamond Creek and Quartermaster areas on motorized

1 22-ft pontoon boats. Under a Memorandum of Understanding between the Hualapai Tribe and
2 the NPS, HRR trips are subject to operational standards required of all NPS river
3 concessionaires.

4
5 HRR currently offers two types of river trips: (1) short 15-minute boat rides above and
6 below the Quartermaster area (RM 260); this services people who have purchased a tour package
7 that generally originates in Las Vegas, in which passengers are ferried to the launch site by
8 helicopter; and (2) 1-day whitewater raft trips that put in at Diamond Creek and take out at
9 Pearce Ferry. Both types of trips also occur during HFEs (Havatone 2013).

10
11 The Tribe authorizes the use of helicopter landing pads (on Reservation lands) both
12 above and below Diamond Creek. The pad near Whitmore (RM 187) is used to exchange
13 passengers from commercial river trips. The helicopter pads at RM 261 are used for day trips
14 that do not involve on-river activities. Helicopter pads at RM 262 and RM 263 are leased to
15 helicopter companies serving HRR river trips, pontoon trips, and trips not involving on-river
16 activities. Noncommercial river rafting passengers do not exchange at these pads.

17
18 The landing at Diamond Creek is a major access point to the river and is a prime take-out
19 location for NPS-permitted river trips originating at Lees Ferry. Approximately 85% of
20 noncommercial river rafting trips and a large percentage of commercial trips end at Diamond
21 Creek (NPS 2006b). Diamond Creek is also the starting point for Hualapai Tribe commercial
22 trips through the lower Grand Canyon and for a few noncommercial trips. The Hualapai Tribe
23 maintains the Diamond Creek road and charges a fee for tourists and river runners entering or
24 exiting the river via this road.

25
26 The Hualapai Tribe has articulated concerns over the operation of Glen Canyon Dam
27 generally and the effects of HFEs specifically (Havatone 2013). This is addressed in
28 Section 4.10.2.7.

31 **3.10.3 Recreation Use on Lakes Mead and Powell**

32
33 Both Lake Mead and Lake Powell are major destinations for boaters, fishermen, and
34 campers. Drought in the Southwest has been having a major impact on both lakes since 2000 and
35 water levels are continuing to decline.

36 37 38 **3.10.3.1 Lake Mead National Recreation Area**

39
40 Lake Mead resulted from the construction of Hoover Dam (once known as Boulder Dam)
41 in 1932. It is the largest reservoir in the United States and at an elevation of 1,221.4 ft AMSL—
42 the elevation of the top of the spillway gates—the reservoir covers 158,500 ac at an elevation of
43 1221.4 ft. The lake extends approximately 110 mi upstream toward the Grand Canyon and about
44 35 mi up the Virgin River. The elevation of Lake Mead on March 1, 2014, was 1107.74 ft AMSL
45 (Reclamation 2014a). On average, visitors at Lake Mead total about 6 million annually.

1 Because of the ongoing drought conditions affecting operations at LMNRA, in
2 October 2005 NPS completed a GMP Amendment for Low Water Conditions and a Finding of
3 No Significant Impact (NPS 2005b) that identified the strategy for low-water operations. This
4 amendment articulated the intent to maintain boat-launch capacities established in the original
5 GMP of 1986 and a subsequent amendment in 2003, by either extending or relocating existing
6 launch ramps and marinas to be functional down to an elevation of 1,050 ft AMSL. This
7 amendment reflects the current management direction for low-water operations, and it assumes
8 that NPS and concessionaires will continue to modify launching and marina facilities as
9 necessary to continue providing visitor services.

10 11 12 **3.10.3.2 Lake Powell, Glen Canyon National Recreation Area**

13
14 Reclamation completed construction of Glen Canyon Dam in 1963; Lake Powell, which
15 was created by the dam, is the second largest reservoir in the United States. The total capacity of
16 the reservoir is 27 million ac-ft, and it stretches for 186 mi. At full-pool elevation, 3700 ft, the
17 reservoir has a surface area of 161,390 ac (NPS 2014e). Lake Powell is subject to the same
18 regional drought conditions as Lake Mead, and the elevation of Lake Powell on March 1, 2014,
19 was 3575.59 ft AMSL (Reclamation 2014a). Annual visitation varies and has been
20 approximately 2 million visitors annually over the past 10 years.

21 22 23 **3.10.4 Park Operations and Management**

24
25 Related to recreation in GCNRA and GCNP is the level of park staffing needed to
26 support recreation and resource protection. The level of staffing affects the ability of the park
27 units to provide appropriate park infrastructure and services to support river and backcountry
28 operations and address visitor experience, and the administrative use of the Colorado River
29 within GCNRA and GCNP. Issues related to park management and operations were raised in
30 public and internal scoping. Some of these issues have been addressed at GCNP by other
31 management documents such as the CRMP (NPS 2006b) and the GCNP General Management
32 Plan (NPS 1995). However, some issues specific to Glen Canyon Dam operations are
33 appropriate for considering within the scope of this EIS. Changes in releases from Glen Canyon
34 Dam may affect the number of personnel, level of funding, and staff time needed to adequately
35 maintain park resources. For example, HFEs require increased staffing resources to notify
36 boaters in Glen and Grand Canyons of high flow releases. In addition, NPS management related
37 to changes in dam operations includes planning, coordination with other agencies,
38 concessionaires, and stakeholders, as well as resource monitoring and visitor safety. Park
39 management and operations may also be affected by non-flow actions.

40
41 The Superintendent of each park is ultimately responsible for park management and
42 operations. In 2014, GCNP employed 512 employees (of which 313 are permanent) to manage
43 operations, including visitor services and facilities, resource management and preservation,
44 planning and environmental compliance, emergency medical services, law enforcement, search
45 and rescue operations, fire operations, air operations, facilities management and maintenance,
46 and administrative functions. Similarly, GCNRA employed 214 employees to manage areas

1 including Lake Powell, surrounding lands, and the 15-mi stretch of Glen Canyon below the dam.
2 These resources include a historic district, a campground, and designated campsites along the
3 river with bathrooms and fire pits.
4

5 Park divisions with river-related responsibilities include facilities management, visitor
6 and resource protection (permits, inner canyon and river rangers, emergency medical services,
7 and search and rescue operations), concessions management (contracts, commercial use
8 authorizations), interpretation and resource education (signage, information, and interpretation),
9 science and resource management (resource protection, inventory, monitoring, research, and
10 research permitting), and the Office of Planning and Compliance (environmental analysis). River
11 recreational and administrative use is currently managed in accordance with the CRMP (NPS
12 2006b), the GCNP General Management Plan (NPS 1995), the GCNRA General Management
13 Plan (NPS 1979), and applicable NPS laws, policies, and regulations.
14
15

16 **3.11 WILDERNESS**

17

18 Approximately 94% of GCNP, or 1,143,918 ac, qualifies as Wilderness as described in
19 the 1964 Wilderness Act and NPS *Management Policies 2006* (NPS 2006d). Grand Canyon
20 Wilderness complements other Designated and Proposed Wilderness Areas north of the Grand
21 Canyon on other NPS, BLM, and USFS lands. Approximately 47% of Glen Canyon, or
22 588,855 ac, was proposed for wilderness designation. This includes 6,180 ac in the Paria unit of
23 the Glen Canyon proposed wilderness.
24
25

26 **3.11.1 Law and Policy**

27

28 The Wilderness Act of 1964 required the Secretaries of Agriculture and the Interior to
29 evaluate land under their jurisdiction for possible wilderness classification. Section 4 of the
30 Wilderness Act describes authorized uses of wilderness areas; subsection 4(a) declares, with
31 specific legislative references, that the Wilderness Act shall be supplemental to the purposes for
32 which the national forests, parks, and refuges have been established. Subsection 4(b) states, in
33 part:
34

35 Except as otherwise provided in this Act, each agency administering any area
36 designated as wilderness shall be responsible for preserving the wilderness
37 character of the area and shall so administer such area for such other purposes for
38 which it may have been established as also to preserve its wilderness character.
39 Thus, except for specified provisions in the legislation, wilderness areas shall be
40 devoted to recreational, scenic, scientific, educational, conservation, and historical
41 uses.
42

43 Subsection 4(c) prohibits certain uses (unless specifically provided elsewhere in the Act)
44 that are inconsistent with wilderness preservation. With the exception of the minimum actions
45 needed for administrative duties and emergency health and safety procedures, the Act prohibits

1 temporary roads, motor vehicle use, motorized equipment or motorboats, landing of aircraft,
2 mechanical transport, structures, and installations.

3
4 Section 4 also addresses special provisions for certain wilderness uses. Subsection 4(d)(1)
5 states, in part:

6
7 Within wilderness areas designated by this Act the use of aircraft or motorboats,
8 where these uses have already become established, may be permitted to continue.
9 These uses are subject to such restrictions as the administering federal official
10 deems desirable. Subsection 4(d)(5) permits the performance of commercial
11 services within wilderness to the extent necessary for activities which are proper
12 for realizing the recreational or other wilderness purposes of this act.

13
14 In addition, NPS Management Policies 2006 (NPS 2006d) includes the following:

15
16 The National Park Service will take no action that would diminish the wilderness
17 suitability of an area possessing wilderness characteristics until the legislative
18 process of wilderness designation has been completed. Until that time,
19 management decision pertaining to lands qualifying as wilderness will be made in
20 expectation of eventual wilderness designation. This policy also applies to
21 potential wilderness, requiring it to be managed as wilderness to the extent that
22 existing non-conforming conditions allow. The National Park Service will seek to
23 remove from potential wilderness the temporary, non-conforming conditions that
24 preclude wilderness designation.

25
26 GCNP and GCNRA are managed as wilderness in accordance with NPS Management
27 Policies and the Wilderness Act of 1964. This area includes the 277-mi section of the Colorado
28 River within the boundaries of GCNP and portions of the Lees Ferry District, including a 15-mi
29 section of the river in GCNRA. The Final EIS for the GCNP Colorado River Management Plan
30 (NPS 2005a) clarifies that recreational motorized use does not preclude possible wilderness
31 designation because such use is a temporary or transient disturbance of wilderness values and
32 does not permanently impact wilderness resources. The 2006 CRMP established a 6.5-month
33 no-motor season to enhance opportunities for a wilderness experience (NPS 2006b).

34
35 NPS wilderness management policy requires that management decisions be consistent
36 with a minimum requirement concept that evaluates the potential disruptions of wilderness
37 character and resources. The minimum requirement concept applies to all administrative
38 activities, including research and monitoring. Research trips of NPS, USGS, and other agencies
39 are subject to the minimum requirement policy.

40 41 42 **3.11.2 Defining Wilderness Character**

43
44 According to GCNP's GMP, areas proposed for wilderness offer visitors opportunities
45 for solitude and primitive recreation. An important provision in the GMP states:
46

1 The management of these areas should preserve the wilderness values and
2 character. Non-wilderness undeveloped areas should continue to serve primarily
3 as primitive thresholds to wilderness. Visitors traveling through the canyon on the
4 Colorado River should have the opportunity for a variety of personal outdoor
5 experiences, ranging from solitary to social. Visitors should be able to continue to
6 experience the river corridor with as little influence from the modern world as
7 possible. The river experience should help visitors to intimately relate to the
8 majesty of the canyon (NPS 1995).

9
10 Subsection 2(c) of the Wilderness Act defines wilderness as follows:

11
12 A wilderness, in contrast with those areas where man and his works dominate the
13 landscape, is hereby recognized as an area where the earth and its community of
14 life are untrammelled by man, where man himself is a visitor who does not remain.

15
16 The same subsection 2(c) further defines wilderness as having the following
17 characteristics:

- 18
19 • Undeveloped land retaining its primeval character in influence without
20 permanent improvements or human habitation
- 21
22 • Generally appears to have been affected primarily by the forces of nature,
23 with the imprint of man's work substantially unnoticeable
- 24
25 • Has outstanding opportunities for solitude or primitive and unconfined type of
26 recreation
- 27
28 • May contain ecological, geological, scientific, educational, scenic, or
29 historical value

30
31 This last quality, recognizing ecological, geological, scientific, educational, scenic, or
32 historical value, is of particular importance when describing the Colorado River and the greater
33 Grand Canyon. To most of the American Indians of the region, the canyon and river represent
34 significant cultural, educational, and historical places that are central to their cultural identity.

35
36 **Wilderness character** is defined in NPS Wilderness Stewardship Reference Manual 41
37 as, "The combination of biophysical, experiential, and symbolic ideals that distinguishes
38 Wilderness from other lands. The five qualities of Wilderness Character are Untrammelled,
39 Undeveloped, Natural, Solitude or a Primitive and Unconfined Type of Recreation, and Other
40 Features of Value."

41
42 All designated wilderness areas, regardless of size, location, or any other feature, are
43 unified by the statutory definition. These four qualities of wilderness are as follows:
44

- 1 1. **Untrammeled**—wilderness is essentially unhindered and free from modern
2 human control or manipulation. This quality pertains to actions that
3 manipulate or control ecological systems.
4
- 5 2. **Natural**—wilderness ecological systems are substantially free from the
6 effects of modern civilization. In the context of managing visitor use on the
7 Colorado River, this quality pertains to the intended and unintended human-
8 caused effects on natural and cultural resources conditions.
9
- 10 3. **Undeveloped**—wilderness is essentially without permanent improvements or
11 modern human occupation. This quality pertains to the presence and
12 development level of trails, campsites, structures, and facilities within the
13 river corridor and areas visited by river users.
14
- 15 4. **Outstanding opportunities for solitude or a primitive and unconfined
16 type of recreation**—wilderness provides outstanding opportunities for people
17 to experience solitude or primitive and unconfined recreation, including the
18 values of inspiration and physical and mental challenge. This quality pertains
19 to visitor opportunities to experience a primitive setting that may include
20 solitude and adventure.
21

22 The fifth quality articulated in the definition of wilderness character above is defined as
23 follows:
24

- 25 5. **Other features of scientific, educational, scenic, or historical
26 value**—attributes not required of or found in every wilderness that reflect a
27 wilderness' specific wilderness character, and is based on the Wilderness
28 Act's Section 2(c) that states a wilderness "may also contain ecological,
29 geological, or other features of scientific, educational, scenic, or historical
30 value."
31

32 This component captures important wilderness elements not covered in the other four
33 Wilderness Character qualities such as cultural or paleontological resources. The three NPS units
34 within the project area protect important cultural histories, significant traditional cultural
35 resources, and extensive archeological records important to preserving the Wilderness Character
36 of the area. The relationship between these qualities and impacts related to Glen Canyon Dam
37 operations are important components of these analyses and will be further discussed in
38 Chapter 4.
39
40
41

1 **3.12 VISUAL RESOURCES**
2

3 Visual resources refer to all objects (man-made and natural, moving and stationary) and
4 features (e.g., landforms, night skies, and water bodies) that are visible on a landscape. These
5 resources add to or detract from the scenic quality of the landscape; that is, the visual appeal of
6 the landscape. Visual impacts can be defined as changes to scenic attributes of the landscape
7 brought about by the introduction of visual contrasts and the associated changes in the human
8 visual experience of the landscape. A visual impact can be perceived by an individual or group
9 as either positive or negative, depending on a variety of factors relating to personal
10 circumstances (e.g., personal experience, aesthetic sensitivity, or the activity in which the viewer
11 is engaged) or to viewing circumstances (e.g., viewing distance, time of day, or weather/seasonal
12 conditions).
13

14 Visual resources are not only important to visitor enjoyment of GCNRA, GCNP, and
15 LMNRA, they are important to American Indian communities who once resided in and/or visited
16 the area for subsistence or ceremonial purposes. Conservation of visual resources is part of the
17 GCPA of 1992 and an important component of the federal management activities for these areas.
18 Scenic resources found within GCNRA, GCNP, and LMNRA include colorful and unique
19 geological formations; complex geology; sleek canyon walls; towering cliffs, buttes, and mesas;
20 rivers, lakes, and streams; barren deserts; and unique prehistoric and historic cultural sites. The
21 scenic resources of these areas are experienced in a number of ways. The canyons have a
22 significant place in the traditional cosmology of the indigenous communities of the Southwest.
23 American Indian communities may visually experience the canyons quite differently than
24 recreational users who experience the canyons not only during recreational activities but also
25 while gathering natural resources or performing religious ceremonies. Water-based recreational
26 activities such as boating, kayaking, swimming, and fishing allow individuals to view the varied
27 landscapes of the Colorado River, Grand and Glen Canyons, Lake Powell, and Lake Mead from
28 almost anywhere on the water. Stewart et al. (2000) found that the more valued aspects of a river
29 rafting trip include simply being in a natural setting, having the opportunity to stop in scenic
30 places, and being able to view flora, fauna, and geology. Terrestrial activities such as hiking and
31 camping along the shores of Lake Powell, Lake Mead, and the Colorado River offer spectacular
32 views, as do designated scenic overlooks accessible via boat, car, or hiking trail. For many
33 Tribes, trails that enter the canyons are sacred and the scenic setting along these trails plays an
34 important part in the travel and ceremonial experience.
35

36 Vegetation also plays an important role in the scenic experience along the Colorado River
37 and in Glen Canyon. Vegetation increases the visual interest of many places by adding variety in
38 color and texture and is also a visual cue for Tribes in determining the health of the ecosystem.
39 For example, sandbars and marshes along the river may contain stands of native vegetation
40 which are important for many Tribal communities. For recreational visitors, native vegetation
41 adds variety in color, texture, and form in contrast to the river and surrounding canyon walls, as
42 well as affording the viewer a chance to see native plant life. Stands of nonnative tamarisk that
43 occur along the river are visual evidence of a nonnative plant species. In addition, nonnative
44 plants may have a different texture than native vegetation, and therefore create visual contrast. A
45 full discussion of plant communities can be found in Section 3.6.
46

1 Hanging gardens are a unique feature formed when springwater flows through cracks in
2 sandstone and seeps out through canyon walls, allowing plants to grow vertically along the walls
3 and on the canyon floor below (Woods et al. 2001). Where visible to visitors, hanging gardens
4 add visual interest through color and texture contrasts with the surrounding bare rock, and they
5 are visually important to Tribes for various reasons.
6
7

8 **3.12.1 Glen Canyon National Recreation Area** 9

10 The deep, 15-mi long, narrow gorge below the dam provides a glimpse of the high
11 canyon walls, ancient rock art, and a vestige of the riparian and beach terrace environments that
12 were a daily experience for American Indians and first recorded in John Wesley Powell’s
13 Colorado River expedition in 1869, providing stark contrast to the impounded canyons of
14 Lake Powell. Portions of this stretch of river are classified as either Class I or Class II scenic
15 areas and are managed as a Natural Zone (NPS 1979). At GCNRA, the Natural Zone is managed
16 for its outstanding scenic resources and relatively undisturbed areas that remain isolated and
17 remote from human activities. Class I scenic areas have outstanding scenic qualities such as
18 “intricately carved landscapes, unique canyons, and unique geological structures,” and Class II
19 scenic areas have a “single property of superior quality or a diversity of form and color.” This
20 stretch of river also includes unique historic and prehistoric sites such as Lees Ferry and Lonely
21 Dell Ranch (NRHP 1997) and the 9-mi Descending Sheep Panel, as well as features such as
22 Paria Beach, the Glen Canyon Dam, and the popular hiking and photographic destination
23 Horseshoe Bend, an “awe-inspiring bend in the Colorado River” where the rocks and river
24 change color throughout the day (NPS 2007; Hughes 2014b). Examples of these resources are
25 shown in Figures 3.12-1 and 3.12-2.
26

27 Dam operations may contribute to effects on visual resources in GCNRA. Lake Powell
28 has restricted access to unique geological formations, such as the famed Cathedral-in-the-Desert,
29 which is now accessible only when water levels are at or below 3,550 ft. Downstream of the
30 dam, HFEs and fluctuations in daily flow can alter the size and shape of sandbars and scour and
31 erode vegetation along the banks of the river, causing changes in landscape forms, lines, colors,
32 and textures, and altering the overall scenic experience of the canyon. Sediment deltas in the
33 headwaters of Lake Powell have formed near the inflows of the Colorado, San Juan, Dirty Devil,
34 and Escalante Rivers (Reclamation 2007a). These are primarily in areas that are also considered
35 Class I and Class II scenic resources. Sediment deltas contribute to changes in form, line, color,
36 and texture and can affect the overall view of the surrounding areas as the reservoir elevation
37 decreases and exposes larger areas of the deltas.
38
39

40 **3.12.2 Grand Canyon and the Colorado River** 41

42 Conserving the Grand Canyon’s scenic resources is an important part of GCNP
43 management goals. The Colorado River falls within GCNP’s Natural Zone which is managed to
44 conserve natural resources and ecological processes while providing for their use by the public,
45 using management techniques that have no adverse effect on scenic quality and natural processes
46 (NPS 1995). Segments of the Colorado River and its tributaries are eligible for Wild and Scenic



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FIGURE 3.12-1 Glen Canyon Viewed from the Colorado River



5
6

FIGURE 3.12-2 Horseshoe Bend (Photo credit: Massimo Tava)

1 River status, although an official determination has not yet been made (NPS 1995). The park's
2 Foundation Statement identified the scenic landscape as a primary interpretive theme and further
3 identified "Scenic Qualities and Values" as components of the fundamental resource "Preserving
4 Visitor Experiences in an Outstanding Natural Landscape" (NPS 2010a). In recognition of its
5 outstanding visual landscapes and its biological and cultural significance, the Grand Canyon was
6 designated as a World Heritage Site in 1979 (UNESCO 2012).

7
8 The Colorado River flows for 277 mi through GCNP. As it flows through the canyon, the
9 river offers spectacular views of complex geology, hardened lava flows, waterfalls, sandy
10 beaches, sheer cliffs, towering buttes, hidden caves, and side canyons (NPS 2013i; Belknap and
11 Belknap-Evans 2012).

12
13 The Colorado River can be seen from many viewpoints accessible along the rims and
14 inner canyon hiking trails. These vantage points offer spectacular panoramas of the Colorado
15 River as it winds through the Grand Canyon. Of the nearly 5 million annual visitors to the
16 Grand Canyon, most view the Colorado River from the rim. Scenic overlooks on the South Rim
17 along the Hermit Rim Road and Arizona State Route 64 include Mohave, Pima, Hopi, Moran,
18 Lipan, and Desert Viewpoints. North Rim overlooks along the scenic road include Point
19 Imperial, Walhalla Overlook, and Cape Royal. The view from the Toroweap Point overlook is
20 one of the most photographed views of the Colorado River (Belknap and Belknap-Evans 2012;
21 Kaiser 2010; Martin 2010; NPS 2015d; Balsom 2014).

22
23 A river trip through the Grand Canyon provides spectacular views of scenic resources
24 along the Colorado River (Figures 3.12-3 and 3.12-4). These include unique cultural sites such as
25 the granaries at Nankoweap (Figure 3.12-4) and Phantom Ranch; exceptionally scenic side
26 canyons and tributaries such as the confluence with the Little Colorado River, Havasu Canyon
27 (Figure 3.12-5), Deer Creek Narrows, Blacktail Canyon, Kanab Creek, and Diamond Creek; and
28 distinctive and colorful geological features caverns, alcoves, grottos, and chasms that range in
29 color from brown, reddish-brown, and orange to light tans and yellows to grays and purples.
30 Redwall Cavern, Elves' Chasm, Vasey's Paradise (Figure 3.12-6), Silver Grotto, Whitmore
31 Wash, Unkar Delta, and Lava Falls are among the most popular scenic geological formations
32 along the river (Belknap and Belknap-Evans 2012; Kaiser 2010; Martin and Whitis 2008).

33
34 Campsites are located along the river's edge on sandy beaches or on ledges and alcoves
35 above the high-water mark. Campsites offer the viewer a chance to see native plant and animal
36 life, in addition to offering views of the Colorado River and surrounding landscape. Many trails
37 are accessible only from these campsites and lead visitors to scenic vantage points of the
38 Grand Canyon and Colorado River (NPS 2010a). See Section 3.11 for a more detailed
39 description of campsites.

40
41 Dam operations may contribute to effects on visual resources along the Colorado River in
42 Grand Canyon. Prior to construction of Glen Canyon Dam, the banks of the Colorado River
43 consisted primarily of open sandy beaches and bare talus slopes with native riparian vegetation
44 established above the elevation of annual scouring flows within the Grand Canyon. These
45 beaches and vegetation were depleted and replenished as the Colorado River picked up and
46 deposited debris during seasonal floods (USGS 2007; NPS 2013i). Currently, the size and shape



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**FIGURE 3.12-3 Typical View of the Colorado River and Grand Canyon
Afforded Recreationists on a River Trip**



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**FIGURE 3.12-4 Colorado River and Granaries at Nankoweap (Photo credit:
Mark Lellouch, NPS)**



FIGURE 3.12-5 Entrance to Havasu Canyon
(Photo credit: Erin Whitaker, NPS)

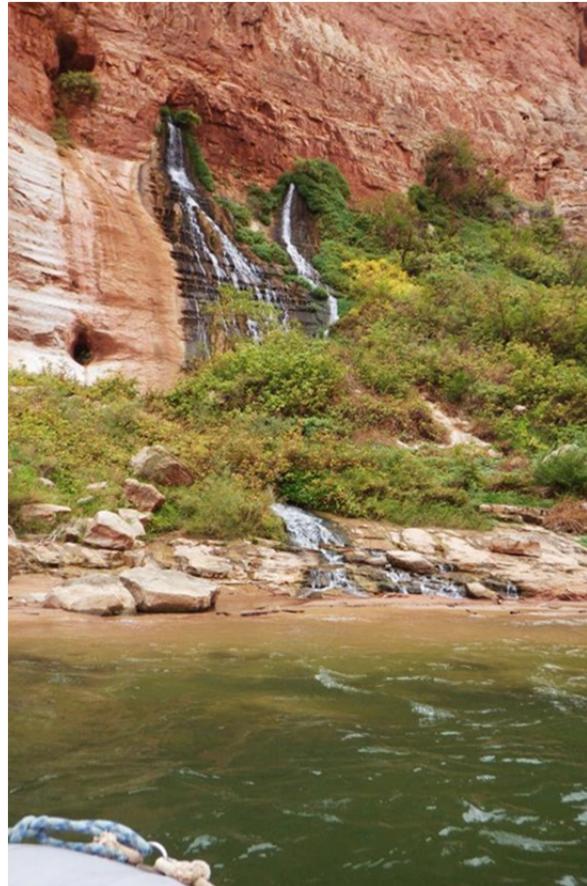


FIGURE 3.12-6 Vasey's Paradise

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of beaches along the river can change frequently with changing river flows and water levels. Much of the sediment that would otherwise move through the canyon is now trapped behind the dam, and regular seasonal flooding does not occur. Because of this, the river lacks the sediment it needs to build up beaches and sandbars, and the beaches sometimes disappear altogether (NPS 2013i). In addition, beaches that are more stable are no longer scoured by occasional flooding, which allows vegetation, including nonnative species such as tamarisk, to take hold and spread (GCMRC 2011). The changes to the size and shape of beaches and the amount and types of riparian vegetation create visual contrasts that may affect visitors' scenic experiences.

Prior to construction of Glen Canyon Dam, the Colorado River carried such a large sediment load that it ran a reddish-brown color throughout the canyon. Now, the river downstream from the dam is relatively clear and green in color. During high releases or after large tributary inputs of suspended sediment, water becomes much more reddish-brown; this effect is ephemeral, however, and water quickly returns to a bluish-green color (NPS 2013g; USGS 2007). Calcium carbonate banding resulting from deposition of minerals at the water edge is also visible in some areas along the Colorado River, typically where the river bank consists of

1 bare rock walls, rocky slopes, or boulders. The changes in water color, depth, and texture may
2 affect the scenic experience of river runners.
3
4

5 **3.12.3 Lake Mead National Recreation Area**

6
7 LMNRA is managed for general recreational purposes to enhance visitor use, while
8 recognizing the importance of and preserving its scenic, historic, and scientific resources
9 (NPS 2002c). Pearce Ferry, located in the northeastern end of the park, serves as the boundary
10 between the Grand Canyon and Lake Mead and marks the final destination for rafting trips down
11 the lower Grand Canyon area. This area is mostly managed as a rural natural setting, where
12 man-made features are present, but natural landscape is predominant.
13

14 Scenic resources within LMNRA include Lake Mead itself and the low, rocky, volcanic
15 hills; steep canyons; and colorful rock formations that surround the reservoir. The surrounding
16 landscape ranges in color from light tans and yellows to bright reds and browns, and contrasts
17 sharply with the striking blue waters of Lake Mead and the bluish-green waters of the Colorado
18 River.
19

20 Sediment deltas resulting from sediment transported through the Grand Canyon have
21 built up in the headwaters of Lake Mead near Peace Ferry (Reclamation 2007a) and Iceberg
22 Canyon (NPS 2015c), areas that are considered rural natural settings. Sediment deltas contribute
23 to changes in form, line, color, and texture that can affect the overall scenic experience of water
24 recreationists and may interfere with management objectives that include the protection of
25 natural-appearing landscapes and pristine views.
26
27

28 **3.13 HYDROPOWER**

29
30 This section describes power operations and power marketing as they relate to
31 Glen Canyon Dam and the Glen Canyon Powerplant. A description of the seven-state
32 socioeconomic environment in which power from the powerplant is marketed is provided in
33 Section 3.14.
34

35 The operation of Glen Canyon Dam and Powerplant directly and indirectly influences the
36 downstream physical environment and aquatic and riparian habitats. For example, the frequency
37 and magnitude of daily fluctuations (for the purposes of following electrical loads and
38 maximizing the value of hydropower) directly affect sediment transport and deposition
39 downstream, directly or indirectly affect aquatic and riparian habitats, affect the recreational
40 environment (beach areas) and use patterns, and indirectly affect air emissions and water
41 consumption for the region.
42

43 Impacts also arise from how power generation from the dam financially affects the
44 U.S. Department of Energy's (DOE's) Western Area Power Administration (Western)
45 customers. When generation from the powerplant is significantly reduced or not timed to match
46 hourly load patterns and Western is unable to fulfill its contractual obligations from existing Salt

1 Lake City Area Integrated Projects (SLCA/IP) resources, Western must purchase power from
2 other market sources to meet any contractual obligations. Those alternate sources are typically
3 derived from power-generation sources fueled by natural gas, coal, oil, nuclear, and to a much
4 lesser degree, solar and wind. Each power-generation source has its own characteristic air
5 emissions, water consumption, and economic impacts. In the event customer contractual
6 allocations are reduced, the customers would be required to replace that capacity and energy
7 from an alternate source through a purchase or build-out of new generation.
8

9 All of the potential impacts noted above are influenced by hourly, daily, monthly, and
10 annual patterns and variations in how water is released from Glen Canyon Dam to produce
11 electricity, and how those releases are typically timed to enhance the value of power generation.
12 Ramp rates (i.e., the rate, in cfs/hr, at which dam releases rise or fall, referred to hereafter as up-
13 ramp rates and down-ramp rates, respectively), flow rates (in cfs), maximum and minimum daily
14 flows (cfs), daily/monthly release volumes (ac-ft), and reservoir elevation (head) are all factors
15 that influence the extent of impacts of dam operations on electrical power customers,
16 downstream environmental resources, Tribal cultural sites, recreational users, and Western's
17 repayment obligations.
18
19

20 **3.13.1 Power Operations**

21
22 Power operations are the physical operations of a large electrical power system, including
23 hydropower generation, and control (operational flexibility, scheduling, load/generation
24 following, regulation, reserves, and transmission).
25
26

27 **3.13.1.1 Hydropower Generation**

28
29 The Glen Canyon Powerplant has eight generators with a maximum combined capacity
30 of 1,320 MW when the reservoir elevation is 3,700 ft AMSL. The maximum combined discharge
31 (water release) capacity of the eight turbines is approximately 31,500 cfs. Under the current
32 operating regime of Modified Low Fluctuating Flow (MLFF) adopted in the 1996 ROD
33 (Reclamation 1996), the maximum release is limited to 25,000 cfs except in extreme hydrologic
34 or emergency conditions. This maximum release restriction limits Glen Canyon Dam power
35 generation capacity to approximately 1,000 MW at a reservoir level of 3,700 ft AMSL, which is
36 76% of potential usable capacity without restriction. The generators require a minimum Lake
37 Powell elevation of 3,490 ft AMSL to operate. At this elevation, the maximum capacity of the
38 Glen Canyon Powerplant is reduced to approximately 630 MW. The annual gross generation has
39 averaged approximately 4.2 million MWh over the period 1989 to 2013, with a minimum annual
40 gross generation of 3.2 million MWh in 2005, and a maximum gross generation of 6.7 million
41 MWh in 1997 (Reclamation 2014b). Because water releases are limited, releases that bypass the
42 generators (such as in the case of most HFEs) not only have no power system economic value,
43 but also detract from turbine water releases, and hence both power production and value.
44

45 Glen Canyon Dam and Powerplant is the largest facility in the Colorado River Storage
46 Project (CRSP), which also includes the Aspinall Unit (Blue Mesa, Crystal, and Morrow Point

1 dams) in Colorado, the Navajo Unit in New Mexico, and Flaming Gorge Dam in Utah. The
2 power produced at these facilities, which includes both capacity and energy⁸ generated at Glen
3 Canyon Dam and other CRSP facilities, is marketed by Western. Net winter and summer energy
4 (adding purchases to the combined powerplant resources and subtracting losses and project use)
5 marketed by Western is currently 2,558 and 2,394 GWh, respectively, while net winter and
6 summer capacity (subtracting project-use loads, system losses, control area regulation needs,
7 firm-load reserves, and scheduled-outage-assistance-loads from generating capability) are
8 1,404 MW and 1,318 MW, respectively. Seasonal variation is due to differences in typical
9 reservoir elevations and project-use loads (Reclamation 1995).

10
11 To coordinate electric power rate-setting and marketing efforts and ensure the timely
12 repayment of federal project construction and irrigation assistance debt, the Colorado River
13 Storage, Collbran, and Rio Grande Projects were administratively integrated in 1987 into the
14 SLCA/IP, which is part of an interconnected generation and transmission system that includes
15 federal, public, and private power generating facilities (Reclamation 1995).

16 17 18 **3.13.1.2 Basin Fund**

19
20 The Upper Colorado River Basin Fund (Basin Fund) was established under Section 5 of
21 CRSPA. CRSPA “authorized a separate fund in the Treasury of the United States to be known as
22 the Upper Colorado River Basin Fund [...] for carrying out provisions of this Act other than
23 Section 8.” Money appropriated for construction of CRSP facilities, except recreation and fish
24 and wildlife facilities constructed under Section 8, is transferred to the Basin Fund from the
25 General Fund of the Treasury. Revenues derived from operation of the CRSP and participating
26 projects are deposited in the Basin Fund. Most of the revenues come from sales of hydroelectric
27 power and transmission services. The Basin Fund also receives revenues from municipal and
28 industrial water service sales, rents, salinity funds from the Lower Colorado Basin (as a pass-
29 through for the Colorado River Basin Salinity Control Program), and miscellaneous revenues
30 collected in connection with the operation of the CRSP and participating projects. Revenues and
31 appropriated funds are accounted for separately in the Basin Fund.

32 33 34 **3.13.1.3 Operational Flexibility**

35
36 The operational flexibility of hydroelectric power generation allows Western to quickly
37 and efficiently increase or decrease generation in response to customer demand, generating unit
38 or transmission line outages (contingency reserves), unscheduled customer deviation from
39 internally scheduled contracted power usage (regulation and load/generation following) within a
40 specific metered load area known as a Balancing Authority (BA),⁹ integrated power system

⁸ Energy (typically measured in MWh) is electricity generated and/or used over time; capacity (typically measured in MW) is total powerplant generation capability.

⁹ Note that in this section of the DEIS, BA is used as the abbreviation for Balancing Authority. In other sections of the DEIS, BA refers to Biological Assessment.

1 requirements, and requests for emergency assistance from interconnected utilities. Under the
2 water release parameters instituted on an interim basis in 1991 and permanently under the
3 1996 ROD following the completion of the Glen Canyon Environmental Impact Statement
4 (Reclamation 1995), Western currently restricts the scheduling of customer contract allocations
5 to two-day-ahead prescheduling only. Ramping restrictions, imposed under the 1996 ROD
6 operating criteria, do not allow generation at Glen Canyon Dam to adjust sufficiently each hour
7 to match the power customer demand schedules. These ramping restrictions result in increased
8 use of alternate generating resources to meet power customer demand schedules. Operational
9 conditions are complicated by the frequency, season, and time of day any of these events may
10 occur; operating restrictions at other CRSP generating facilities and within the interconnected
11 electric system; and the availability and price of alternative power resources (Reclamation 1995).

12
13 Although there is considerable potential for flexibility in Glen Canyon powerplant
14 operations, current operating criteria have placed multiple restrictions on the variability of water
15 released from the dam, thus restricting operations at the powerplant. Prior to 1991, Reclamation
16 operated the dam and powerplant to maintain a minimum release of 3,000 cfs in summer months,
17 and maintained a 1,000-cfs limit minimum flow for the remainder of the year. There were no
18 restrictions on ramp rates, and daily fluctuations were occasionally as high as 28,500 cfs in the
19 summer months and 30,500 cfs for the rest of the year (Poch et al. 2011). Beginning in
20 August 1991, an Interim Flows decision restricted the operation of the dam for environmental
21 reasons, and the Interim Flows decision was used as the basis for operation until February 1997,
22 when the February 1997 operating criteria, based on the 1996 ROD, restricted dam operational
23 flexibility. This operating regime, referred to as MLFF is currently used as the basis of
24 operations at Glen Canyon Dam and requires water release rates to be 8,000 cfs or greater
25 between the hours of 7 a.m. and 7 p.m., and at least 5,000 cfs at night. The criteria also limit
26 ramp rates; the maximum hourly increase (i.e., the up-ramp rate) is 4,000 cfs/hr, and the
27 maximum hourly decrease (i.e., the down-ramp rate) is 1,500 cfs/hr. The 1996 ROD operating
28 criteria also restricted the extent to which releases can fluctuate during a rolling 24-hour period.
29 This change constraint varies between 5,000 cfs/day and 8,000 cfs/day, depending on the
30 monthly volume of water releases. Daily fluctuation is limited to 5,000 cfs in months when less
31 than 600 thousand acre-feet (kaf) is released. The fluctuation limit increases to 6,000 cfs when
32 monthly release volumes are between 600 kaf and 800 kaf. When the monthly water release
33 volume is 800 kaf or higher, the daily allowable fluctuation is 8,000 cfs (Reclamation 1995;
34 Poch et al. 2011). MLFF includes emergency exception criteria.

35
36 Under MLFF, the maximum release rate for power generation is limited to 25,000 cfs.
37 Maximum release rate exceptions are allowed if needed to avoid spills or flood releases during
38 high runoff periods. Under very wet hydrologic conditions, defined as when the average monthly
39 release rate is greater than 25,000 cfs, the flow rate may be exceeded, but water must be released
40 at a constant rate. Adjustments to MLFF are made to avoid spills, during flood releases, to
41 accommodate experimental releases, and to accommodate electrical emergencies. These
42 adjustments include maximum release rates above 25,000 cfs. Experimental releases may
43 occasionally require release rates in excess of the capacity of the powerplant. When this situation
44 occurs, additional water would be released through bypass tubes to achieve the desired high
45 release rate. Bypassing water around the generators produces no energy, which can result in
46 additional purchases of replacement power, and increases the river stage in the tailwater, which

1 reduces elevation, thereby reducing the effective head and power conversion rates for water
2 passing through powerplant turbines (Poch et al. 2011).

3 4 5 **3.13.1.4 Scheduling**

6
7 Power scheduling is the matching of seasonal, daily, and hourly system energy and
8 capacity needs with available generation. At Glen Canyon Dam, power scheduling is affected by
9 the distribution of monthly water release volumes, restrictions in water release patterns
10 (maximum and minimum release limits, allowable daily fluctuation rates, and hourly ramp rates),
11 availability of the eight units in the Glen Canyon Powerplant and other CRSP units (individual
12 units are on a rotating maintenance schedule) in the system, power customer allocations, and
13 peak and off-peak power periods. Weather and runoff forecasts, alternate resource availability,
14 and the market price of electricity also play important roles in how the customers schedule their
15 allocation of CRSP resources (Reclamation 1995).

16
17 Scheduling to meet power requirements generally means higher water releases in peak
18 months when the demand for power (load) is higher (December, January, July, and August) and
19 lower water releases when electric power demand is lower, allowing Western to take advantage
20 of market conditions for purchases.

21
22 Prior to 1990, dispatch (the sequence in which SLCA/IP powerplants are utilized to meet
23 the demand for electricity) from powerplants was driven primarily by market prices. A high level
24 of operating flexibility at the SLCA/IP allowed Western to purchase energy during off-peak
25 periods to meet customer demand, storing the water for later power generation during on-peak
26 periods when prices were higher. Accordingly, Western was able to maximize the economic
27 value of electricity sales from the Glen Canyon Powerplant. Since MLFF operational constraints
28 were imposed on SLCA/IP resources, including those at Glen Canyon Dam, SLCA/IP
29 powerplants have been dispatched independently to meet contractual obligations at the lowest
30 possible cost, with the lowest variable operating costs generally dispatched first, and plants with
31 higher variable operating costs brought online sequentially as electricity demand increases.
32 Hourly differences between loads and resource production are reconciled through market
33 purchases and sales. Within the operational restrictions of MLFF, there are many hourly release
34 patterns and dispatch arrangements that comply with the operating criteria to provide scheduling
35 flexibility to meet power customer demand. However, since the implementation of MLFF,
36 between 1997 and 2005, the average annual cost incurred ranged from \$38 million to
37 \$50 million, due to operational restrictions (Veselka et al. 2010).

38 39 40 **3.13.1.5 Load/Generation Following and Regulation**

41
42 To ensure interconnected system reliability, Western follows mandatory reliability
43 standards enforced by the North American Electric Reliability Corporation (NERC) and the
44 Western Electricity Coordinating Council (WECC). In addition, Western follows operational
45 criteria, guidelines, and procedures set in place by the WECC and the contingency Reserve
46 Sharing Group (RSG) applicable to each BA. Each WECC utility is located within such a load

1 control area, and one utility within the BA serves as the BA operator. Western is the BA operator
2 for the Western Area Lower Colorado Region (WALC) BA, the Western Area Colorado-
3 Missouri Region (WACM) BA, and the Western Area Upper Great Plains West Region
4 (WAUW) BA, and is responsible for ensuring that each load-serving utility within each BA
5 serves its own internal load while meeting its power and reserve obligations. Operating as a BA,
6 Western is the provider of last resort should a load-serving entity not be able to fulfill its
7 obligation to the BA, and it carries all compliance responsibility for the BA function. All CRSP
8 powerplants are within the WACM BA, and the flexibility and load/generation following
9 capability of CRSP hydroelectric powerplants, particularly Glen Canyon Powerplant, are
10 important in meeting NERC/WECC reliability standards and criteria.

11
12 Hydropower generation is valuable because it can react instantaneously to changes in
13 load or unanticipated changes in generation resources within the BA. This ability to respond to
14 rapidly changing load conditions is called load and/or generation following regulation. As a BA
15 operator, Western utilizes its hydrogeneration resources, and hydropower is typically used to
16 balance instantaneous changes to loads and/or generation within the metered transmission and
17 generation BA system. By comparison, coal- and nuclear-based resources have a very slow
18 response time, and consequently have limited load/generation following regulation capability.
19 Load/generation following regulation capability at Glen Canyon Dam is limited to ± 40 MW and
20 is outside the 1996 ROD operating criteria ramping restrictions.

21
22 In general, power demand increases during the daylight hours as residences, commercial
23 establishments, agriculture, and industrial electrical demands increase. Under normal conditions,
24 the system load pattern throughout the region is similar from Monday through Friday, but load
25 often drops considerably on Saturday and Sunday as companies with a heavy commercial or
26 industrial load shut down. System load also varies seasonally with increases in the conditions
27 load in December, January, July, and August and lower demand for power in the remaining
28 months (Reclamation 1995).

29
30 Implementation of the 1996 ROD operating criteria has reduced the ability of power
31 generation at Glen Canyon Dam to follow hourly changes in customer load. Prior to the 1990s,
32 power generation from CRSP powerplants, including Glen Canyon Dam, was driven primarily to
33 meet daily and seasonal power demands. A high level of operating flexibility at these federal
34 facilities allowed power generation to closely follow on- and off-peak electrical loads which
35 made these federal facilities valuable assets in developing the economies of the Western
36 United States. For example, during the 1978 energy crisis, Glen Canyon Dam was operated
37 under an executive order that required federal agencies to exercise their authorities to increase
38 domestic energy production and reduce U.S dependence on foreign oil. Accordingly, Western
39 was able to increase the economic value of electricity deliveries to its electrical customers using
40 generation at Glen Canyon Dam and its other facilities in the CRSP unit to meet this directive.
41 Beginning in the 1990s, however, operations at each of the CRSP powerplants (Glen Canyon
42 Dam in 1996, Flaming Gorge Dam in 2005, Navajo Dam in 2006, and the Aspinall Unit in 2012)
43 have been restricted for environmental reasons. Although Western continues to dispatch these
44 units to maximize load following capabilities within the constraints each unit operates under,
45 these restrictions have substantially reduced the usable generation capacity of these facilities to
46 meet the daily and seasonal energy needs of its customers.

1 In addition to load/generation following and regulation responsibilities, dispatchers
2 follow other practices that are specific to Glen Canyon Dam Powerplant operations. These
3 practices fall within MLFF constraints but are not ROD requirements and may be altered or
4 abandoned by Western at any time. One practice involves reducing generation at Glen Canyon
5 Dam to the same minimum level every night during low-price, off-peak hours. Western also
6 avoids large changes to total daily water volume releases when they occur over successive days.
7 This increases the efficiency of producing and marketing power at the dam and reduces
8 downstream environmental impacts. In addition, weekend releases are generally not less than
9 85% of the average weekday release and, during the summer season, one cycle of raising and
10 lowering Glen Canyon Dam Powerplant output, increasing to a maximum of two cycles during
11 other seasons of the year as dictated by the hourly load pattern provided by customer
12 preschedules (Poch et al. 2011).

13
14 Changes in Western's scheduling guidelines typically occur slowly over a period of
15 months, not only because of the operational constraints imposed by the ROD, but also due to
16 changing market conditions, such as persistent drought, electricity market disruptions in
17 2000 and 2001, and extended experimental releases that have large daily flow rate fluctuations
18 (Poch et al. 2011).

21 **3.13.1.6 Capacity Reserves**

22
23 Each BA, or RSG utility applicable to it, is required to maintain sufficient generating
24 capacity to continue serving its customer load, even if the BA or RSG utility loses all or part of
25 its own largest generating unit or largest capacity transmission line. This is done to ensure
26 electrical service reliability and uninterrupted power supply. Reserve requirements for the
27 generation resources of the SLCA/IP are based on a formula which considers the loss of the
28 largest single generator within the Rocky Mountain RSG and allocates a reserve quota to each
29 member based on their relative size within the group. Total available capacity, in turn, is
30 determined by the minimum and maximum allowable releases from these powerplants. Spinning
31 reserves (generating units that are operating online but not generating electricity) are used to
32 quickly replace lost electrical generation resulting from a forced outage, such as the sudden loss
33 of a major transmission line or generating unit. Additional offline reserves (offline idle units that
34 are ready to begin generating electricity) can be used to replace generation shortages, but they
35 cannot respond as quickly as spinning reserves (Reclamation 1995). SLCA/IP generation
36 resources are located within the Rocky Mountain RSG. A portion of that generation is set aside
37 by the Rocky Mountain RSG to be utilized during contingency reserve activation periods.
38 Capacity for this reserve obligation is held on Glen Canyon generation resources by Western
39 whenever possible. (Reserve activations and subsequent water releases through the generators
40 are not subject to the 1996 ROD release criteria.)

43 **3.13.1.7 Disturbances and Emergencies and Outage Assistance**

44
45 In the event of a widespread sudden loss of generation resource power outage, or an
46 imbalance in the transmission system element causing a load/resource imbalance requiring an

1 immediate response (i.e. disturbance), NERC contingency reserve standards require that available
2 generation capacity be utilized to return the electric generation and transmission system to
3 normal operating conditions within load/generation balance within 10 minutes following the
4 disturbance. Generally, emergency operations contingency reserves are needed only for periods
5 of an hour or less, but can and frequently are activated several times a day. Western also has
6 existing contractual agreements to use capacity at Glen Canyon Dam to restart traditional
7 thermal powerplants and provide emergency shutdown power to nuclear powerplants. It is
8 especially important for generation resources at Glen Canyon Dam to be available for safe
9 shutdown of nuclear facilities in the area in the unlikely event of a widespread power outage.
10 Western's ability to supply emergency assistance is limited by available transmission capacity
11 and available generation capability, while the ability to deliver emergency assistance varies on
12 an hourly basis, depending on firm load obligations and available generation from project
13 resources. With a full reservoir and average loads, Glen Canyon Dam and Powerplant has
14 been able to provide emergency assistance beyond its required reserves by utilizing its
15 remaining unloaded capacity after serving load, regulation, frequency response, and
16 contingency reserve obligations. Due to the flexibility of hydroelectric resources, the SLCA/IP
17 has often provided scheduled outage assistance. This ability will continue into the future under
18 all potentially selected alternatives of the LTEMP DEIS. Responding to electrical emergencies
19 also is not subject to the 1996 ROD operating constraints.
20

21 22 **3.13.1.8 Transmission System** 23

24 The CRSP/WACM transmission system is used to transmit electricity from Glen Canyon
25 Dam and other generating sources to customer utilities that serve end users such as municipal,
26 residential, Tribal, irrigation district, and commercial and industrial consumers. Both
27 hydroelectric generation and other generation resources are affected by transmission limitations
28 when lines do not have enough capacity to transmit electricity from the point of generation to the
29 point of demand. The amount of power scheduled for transmission varies from season to season,
30 day to day, and hour to hour. Scheduling limits are derived from physical limits and determine
31 how many transactions may occur. Actual transmission refers to the measured flow of power on
32 the line. NERC requires monitoring of the actual and scheduled power flow for system operation
33 (Reclamation 1995).
34

35 36 **3.13.2 Power Marketing** 37

38 Electricity generated at Glen Canyon Dam and Powerplant and other SLCA/IP facilities
39 in the Upper Colorado Region is marketed by Western under statutory criteria in the Reclamation
40 Project Act of 1939, the Flood Control Act of 1944, the Colorado River Storage Project Act of
41 1956 (CRSPA), and the Department of Energy Organization Act of 1977, along with associated
42 marketing plans and contractual obligations. Requirements stemming from these criteria include:
43

- 44 • Preference in the sale of capacity and energy must be given to municipalities,
45 public corporations, cooperatives, and other nonprofit organizations.
46

- 1 • Capacity and energy must be marketed at the lowest possible rates consistent
2 with sound business practices.
- 3
- 4 • Revenues generated from capacity and energy sales must pay for power
5 generation and transmission facility costs (including operations, maintenance,
6 replacements, and firming purchases and emergency power) and all allocated
7 investment costs under the CRSPA, including interest and irrigation project
8 expenses and investment costs related to regulating water deliveries, flood
9 control, and water storage beyond the ability of the irrigators to repay, as well
10 as certain environmental costs as provided under the Grand Canyon Protection
11 Act of 1992 (GCPA).
- 12
- 13 • Projects must generate the greatest practicable amount of capacity and energy
14 that can be sold at firm power and energy rates.
- 15
- 16 • Western is responsible for the construction, operation, and maintenance of
17 transmission lines and attendant facilities.
- 18

19 Western markets wholesale CRSP power to preference entities serving approximately
20 5.8 million retail customers in Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming
21 (Reclamation 2012d). Customers are small and medium-sized municipalities that operate
22 publicly owned electrical systems; irrigation cooperatives and water conservation districts; rural
23 electrical associations or generation and transmission co-operatives who often act as wholesalers
24 to these associations; federal facilities such as Air Force bases, universities, and other state
25 agencies; and Indian Tribes (Reclamation 2012d).

26

27 For Western's eight largest customers in 2013, the SLCA/IP provided 6.1% of energy
28 and 4.7% of capacity requirements; the remaining 93.9% of energy and 95.3% of capacity being
29 provided by customer utility-owned generation facilities, or purchased from investor-owned or
30 other utility systems, as well as other federal hydropower projects marketed by Western.
31 Reliance on SLCA/IP capacity and energy varies considerably among customers; Navajo Tribal
32 Utility Authority (27.4%) and Utah Municipal Power Agency (25.7%) received more than 25%
33 of their energy from SLCA/IP in 2009, while three utilities, Navajo Tribal Utility Authority
34 (19.1%), Utah Municipal Power Agency (17.8%), and Deseret Generation and Transmission
35 Cooperative (17.8%), relied on Western for more than 15% of their capacity (Table 3.13-1).
36 Other utilities, such as Tri-State G&T (1,537 GWh and 235 MW), received larger energy and
37 capacity allocations but relied on Western for only a small portion of their total capacity and
38 energy requirements.

39

40 Western markets long-term firm capacity and energy, short-term firm capacity and
41 energy, and non-firm energy. Firm power is capacity and energy that are guaranteed to be
42 available to the customer. Loads are made up of firm load, non-firm sales, and interchanges out
43 of the control area. Firm load and capacity obligations include long- and short-term firm sales,
44 Reclamation project use loads, system losses, BA control area regulation, firm load contingency
45 reserves, and scheduled outage assistance. Capacity is reserved to provide regulation,

1 **TABLE 3.13-1 Energy and Capacity Characteristics of the Eight Largest Western Customers,**
 2 **2013^a**

Customer Utility	Energy Required (GWh)	Energy from Western (GWh)	Percentage of Energy from Western	System Peak Load (MW)	Western Allocation (MW)	Percentage of Load from Western
Colorado Springs Utilities	4,968	140	2.8	908	22	2.4
Deseret Generation and Transmission Cooperative	2,497	447	17.9	391	70	17.8
Navajo Tribal Utility Authority	718	197 ^b	27.4	140 ^b	27	19.1
Platte River Power Authority	3,196	536	16.8	659	71	10.7
Salt River Project	32,452	290	0.9	6,663	42	0.6
Tri-State G&T	15,313	1,537	10.0	2,666	235	8.8
Utah Municipal Power Agency	1,216	312	25.7	265	47	17.8
Utah Associated Municipal Power Systems	3,884	477	12.3	943	75	8.0
All eight customers	64,243	3,937	6.1	12,635	588	4.7

^a Data on energy requirements and system peak load are actual values for 2013, except data for Deseret Generation and Transmission Cooperative and Navajo Tribal Utility Authority, which are forecasts for 2013.

^b Does not include allocations received by Navajo Tribal Utility Authority from Western on behalf of 13 other Tribal groups.

Sources: Colorado Springs Utilities (2015); Deseret Power Cooperative (2012); Navajo Tribal Utility Authority (2012); Platte River Power Authority (2015); Salt River Project (2015); Tri-State G&T (2015); Utah Municipal Power Agency (2015); Utah Associated Municipal Power Systems (2015); Osiek (2015).

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1 contingency reserves, frequency support and response, meet CRSP contractual obligations,
2 participating project capacity, and serve Reclamation's irrigation and drainage pumping plant
3 loads before being marketed as long-term firm capacity. Western's ability to make non-firm
4 energy sales with hydrogeneration resources after all firm power obligations have been met, and
5 there are generation resources available for marketing purposes as water release requirements
6 dictate, depends on SLCA/IP's flexibility to take advantage of on-peak and off-peak spot energy
7 markets (Reclamation 1995).
8

9 The majority of CRSP power is sold under long-term firm electric service contracts. If
10 Western is unable to supply contracted amounts of firm capacity or energy from Reclamation
11 hydroelectric resources, it must purchase the deficit from other (primarily non-hydropower)
12 resources for delivery. The expense for this purchased power is shared by all SLCA/IP
13 customers.
14

15 Non-firm sales are short-duration energy transactions that are always less than 1 year.
16 Normally scheduled 1 day in advance, although transactions can occur hourly, they can be
17 determined up to the hour of transaction. These non-firm sales occur when generation patterns
18 associated with the 1996 operating criteria do not match customer load schedules and cannot be
19 used for firm electricity deliveries. Western sells the excess generation on the non-firm market to
20 accommodate release obligations. The flexibility of hydropower operations allows actual
21 deliveries to be modified hourly, as system conditions warrant. Western may market non-firm
22 energy and arrange for interchange transactions, depending on revised water release estimates.
23 Non-firm capacity and energy are capacity and energy that are not guaranteed to be available to
24 the customer, and are purchased by wholesale customers that prefer non-firm energy that is less
25 expensive than power generated at their own powerplants or by alternative supply sources. Non-
26 firm energy is usually sold with the caveat that the sale can be stopped on short notice and the
27 buyer must have the resources available to meet its own load. Non-firm energy is sold at a
28 negotiated price and delivery point based on market conditions. Rates for non-firm energy only
29 include a charge for the energy delivered, since the customer has the capacity to meet its loads if
30 necessary. Western does not sell non-firm energy on a long-term basis. The price for non-firm
31 energy is based on market conditions (Reclamation 1995).
32

33 Western also offers both firm and non-firm transmission service. Firm transmission
34 service is contractually guaranteed for the term of the agreement. Non-firm transmission service
35 is provided as available and is not guaranteed. Western participates in electricity transfers, which
36 occurs when two indirectly connected utilities agree to purchase or sell power to each other. The
37 purchaser or seller must make arrangements to use the transmission system that connects them.
38 Western offers wheeling transmission service over particular CRSP transmission paths, including
39 lines carrying power from Glen Canyon Dam. Non-firm transmission service, like non-firm
40 power sales, can be interrupted on short notice (Reclamation 1995).
41
42

43 **3.13.2.1 Wholesale Rates** 44

45 Western has long-term firm electric service contracts for SLCA/IP power with 138 Tribal
46 entities and wholesale customers (including municipal utilities, federal and state public power

1 facilities, and rural electric cooperatives). Power rates are established in order that revenues will
2 be sufficient to pay all costs assigned to power within required time periods. Power revenues also
3 pay annual power operation and maintenance, purchased power, transmission service, and
4 interest expenses on Treasury loans used to finance construction of Western hydropower
5 projects, as well as irrigation assistance beyond the ability of the irrigators to repay, along with
6 various environmental costs, including costs of the GCDAMP and the Upper Colorado River and
7 San Juan River Endangered Fish Recovery Implementation Programs. CRSP power revenues
8 also must contribute toward salinity control costs under the Colorado River Basin Salinity
9 Control Act and construction costs (with interest) of CRSP participating projects as well as
10 certain environmental costs as provided under the GCPA. Any remaining annual revenues are
11 used to pay off investment costs assigned to power, so that each investment can be paid within
12 the time allowed (Reclamation 1995).

15 **3.13.2.2 Retail Rates**

17 Retail rates are those paid by end users (residential, commercial, and industrial customers
18 of Western's wholesale customers). The retail rates charged by not-for-profit entities normally
19 are set to cover system operation and capital costs. As costs of these individual components
20 change, the retail rates are adjusted to ensure enough revenue is collected to meet the utility's
21 financial obligations

24 **3.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE**

26 This section provides a brief socioeconomic background for two regions of influence: a
27 six-county region in which the majority of recreation in the Grand Canyon area occurs and a
28 seven-state region in which power from the Glen Canyon Powerplant is marketed. Five standard
29 measures of economic development are described in the following sections: (1) population,
30 (2) income, (3) total employment, (4) employment by sector, and (5) unemployment. A brief
31 description of the numbers and locations of minority and low-income populations, including
32 Tribal populations, in an 11-county region is also provided.

35 **3.14.1 The Six-County Region of Influence**

37 The six-county region is composed of Coconino County and Mohave County in Arizona,
38 and Garfield County, Kane County, San Juan County, and Washington County in Utah.
39 Additional socioeconomic background information on these counties can be found in
40 DOI (2012a). Clark County, Nevada, was not included in the recreational economics analysis
41 presented here. Although it is likely that there is some recreational expenditure in Clark County
42 associated with recreation in Lake Mead, the share of these expenditures occurring in Clark
43 County is not known. Expenditures were assumed to occur only in the six counties included in
44 the analysis.

3.14.1.1 Population

Table 3.14-1 presents recent and projected populations in the region and states as a whole. The population in the region stood at 511,435 in 2012, having grown at an average annual rate of 2.4% since 2000. Washington County (4.0%), Mojave County (2.3%), and Kane County (1.5%) experienced higher growth rates than the remainder of the region, with lower growth rates in Garfield County (0.6%) and San Juan County (0.3%). The population growth rate for the region (2.4%) was slightly higher than the rates for both Arizona and Utah (2.1%) between 2000 and 2012.

The population in the region is expected to increase to 612,126 by 2020 and 753,124 by 2030.

3.14.1.2 Income

Personal income in the region stood at \$15.1 billion in 2011 and grew at an annual average rate of 3.1% over the period from 2000 to 2011 (Table 3.14-2). Personal income per capita in the region also rose over the same period at a rate of 0.6%, increasing from \$27,990 to \$29,842. Per-capita incomes were higher in Coconino County (\$35,685) and Kane County (\$32,989) in 2011 than the average for the region as a whole. The rate of growth in personal income in the region (3.1%) was higher than the rates for Arizona (2.3%) and the same as that for Utah (2.5%) as a whole.

TABLE 3.14-1 Population in the Six-County Region

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012	2020	2030
Coconino County, Arizona	116,320	136,011	1.3	144,300	154,400
Garfield County, Utah	4,735	5,095	0.6	6,063	6,821
Kane County, Utah	6,046	7,221	1.5	8,357	10,259
Mohave County, Arizona	155,032	203,334	2.3	241,000	285,600
San Juan County, Utah	14,413	14,965	0.3	15,644	15,486
Washington County, Utah	90,534	144,809	4.0	196,762	280,558
Six-County Region	386,900	511,435	2.4	612,126	753,124
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Governor’s Office of Planning and Budget (2013).

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28

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TABLE 3.14-2 Income^a in the Six-County Region

Location	2000	2011	Average Annual Growth Rate (%), 2000–2011
<i>Coconino County, Arizona</i>			
Income (billions of 2013\$)	3.8	4.8	2.2
Per-capita income (2013\$)	32,298	35,685	0.9
<i>Garfield County, Utah</i>			
Income (billions of 2013\$)	0.1	0.1	1.6
Per-capita income (2013\$)	25,680	28,007	0.8
<i>Kane County, Utah</i>			
Income (billions of 2013\$)	0.2	0.2	2.5
Per-capita income (2013\$)	30,195	32,989	0.8
<i>Mohave County, Arizona</i>			
Income (billions of 2013\$)	4.1	5.5	2.7
Per-capita income (2013\$)	26,249	27,045	0.3
<i>San Juan County, Utah</i>			
Income (billions of 2013\$)	0.3	0.3	2.6
Per-capita income (2013\$)	17,866	23,148	2.4
<i>Washington County, Utah</i>			
Income (billions of 2013\$)	2.4	4.1	4.8
Per-capita income (2013\$)	27,019	28,915	0.6
<i>Six-County Region</i>			
Income (billions of 2013\$)	10.8	15.1	3.1
Per-capita income (2013\$)	27,990	29,842	0.6
<i>Arizona</i>			
Income (billions of 2013\$)	183.6	235.4	2.3
Per-capita income (2013\$)	35,778	36,397	0.2
<i>Utah</i>			
Income (billions of 2013\$)	74.4	97.8	2.5
Per-capita income (2013\$)	33,333	34,738	0.4

^a Per-capita income is income per person.

Source: U.S. Department of Commerce (2013).

2
3
4

1 Average per-capita incomes in 2012 in the six-county region were lower than the
 2 averages for Arizona (\$36,397) and Utah (\$34,738).

3
 4 Median household incomes (the income level at which exactly half of all households earn
 5 more than the level, and half earn less) over the period 2008 to 2012 varied between \$42,074 (in
 6 2013 dollars) in Mohave County and \$51,622 in Coconino County (U.S. Census Bureau 2013a).
 7 Median household incomes were \$50,101 for Arizona and \$60,576 for Utah over the same
 8 period.

9
 10
 11 **3.14.1.3 Employment**

12
 13 In 2012, employment in the region stood at 207,673 (Table 3.14-3). Over the period from
 14 2000 to 2012, annual average employment growth rates were higher in Washington County
 15 (3.0%) and Mohave County (1.3%) than elsewhere in the region. At 1.6%, growth rates in the
 16 region as a whole were slightly higher than the average rates for Arizona (1.2%) and Utah
 17 (1.3%).

18
 19 In 2011, the service sector provided the highest percentage of employment in the region
 20 at 53.9%, followed by wholesale and retail trade (22.3%) (Table 3.14-4). Smaller employment
 21 shares were held by manufacturing (6.6%) and construction (5.6%). Within the region, county-
 22 level employment varied somewhat across sectors compared with the region as a whole. Garfield
 23 County had a higher percentage of employment in agriculture (18.7%) and services (64.4%) than
 24 the region as a whole, while manufacturing in Coconino County (8.3%), wholesale and retail
 25 trade in Mohave County (26.6%), and services in Kane County (76.2%) were more important as
 26 employment sources than in the region as a whole.

27
 28
 29 **TABLE 3.14-3 Employment in the Six-County Region**

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012
Coconino County	59,739	67,052	1.0
Garfield County	2,301	2,454	0.5
Kane County	2,896	3,098	0.6
Mohave County	65,589	76,733	1.3
San Juan County	4,324	4,449	0.2
Washington County	37,771	53,887	3.0
Six-County Region	172,620	207,673	1.6
Arizona	2,404,916	2,778,579	1.2
Utah	1,097,915	1,276,249	1.3

Source: U.S. Department of Labor (2013).

1

TABLE 3.14-4 Employment by Sector in 2011^a

Employment Sector	Coconino County		Garfield County		Kane County		Mohave County	
	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture ^a	628	1.4	260	18.7	141	6.3	265	0.7
Mining	60	0.1	10	0.7	10	0.4	556	1.4
Construction	1,932	4.3	60	4.3	76	3.4	1,932	4.8
Manufacturing	3,750	8.3	60	4.3	60	2.7	2,552	6.4
Transportation and public utilities	1,658	3.7	20	1.4	70	3.1	1,551	3.9
Wholesale and retail trade	8,563	19.0	176	12.6	369	16.5	10,645	26.6
Finance, insurance, and real estate	1,628	3.6	23	1.7	70	3.1	1,724	4.3
Services	25,722	57.0	896	64.4	1,702	76.2	20,744	51.9
Other	10	0.0	0	0.0	0	0.0	12	0.0
Total	45,143		1,392		2,234		39,998	

Employment Sector	San Juan County		Washington County		Six-County Region	
	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture ^a	226	8.3	381	1.0	1,901	1.5
Mining	110	4.0	60	0.2	806	0.6
Construction	164	6.0	2,953	8.1	7,117	5.6
Manufacturing	175	6.4	1,896	5.2	8,493	6.6
Transportation and public utilities	75	2.7	2,624	7.2	5,998	4.7
Wholesale and retail trade	492	18.0	8,236	22.6	28,481	22.3
Finance, insurance, and real estate	99	3.6	1,830	5.0	5,374	4.2
Services	1,475	53.9	18,511	50.7	69,050	53.9
Other	0	0.0	1	0.0	23	0.0
Total	2,738		36,485		127,990	

^a Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

3-205

3.14.1.4 Unemployment

Unemployment rates varied across the five counties in the region. Between 2000 and 2012, the average rate in San Juan County was 8.9% and 8.3% in Garfield County, with a relatively high rate of 6.8% in Mohave County (Table 3.14-5). The average rate in the region over this period was 6.4%, which was higher than the average rates for Arizona (5.2%) and Utah (4.0%). Unemployment rates were higher in 2012 than the average rates for the period from 2000 to 2012, with higher rates of 10.7% in San Juan County, 10.5% in Garfield County, and 9.9% in Mohave County. The average rates in 2012 for the region (8.6%) and for Arizona (8.3%) and Utah (5.7%) were also higher than the corresponding average rates for 2000 to 2012.

TABLE 3.14-5 Unemployment Rates (%) in the Six-County Region

Location	Average Growth Rate (%), 2000–2012	2012
Coconino County, Arizona	6.1	8.1
Garfield County, Utah	8.3	10.5
Kane County, Utah	5.5	7.2
Mohave County, Arizona	6.8	9.9
San Juan County, Utah	8.9	10.7
Washington County, Utah	5.7	7.0
Six-County Region	6.4	8.6
Arizona	5.2	8.3
Utah	4.0	5.7

Source: U.S. Department of Labor (2013).

3.14.1.5 Environmental Justice

E.O. 12898, “Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations” (*Federal Register*, Vol. 59, p. 7629, Feb. 11, U.S. President 1994b), formally requires federal agencies to incorporate environmental justice as part of their missions. Specifically, it directs them to address, as appropriate, any disproportionately high and adverse human health or environmental effects of their actions, programs, or policies on minority and low-income populations.

The analysis of the impacts of changes in the operation of hydropower facilities on environmental justice issues follows guidelines described in the Council on Environmental Quality’s (CEQ’s) *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). The analysis method has three parts: (1) the geographic distribution of

1 low-income and minority populations in the affected area is described; (2) an assessment is
2 conducted to determine whether the impacts of changes in operation would produce impacts that
3 are high and adverse; and (3) if impacts are high and adverse, a determination is made as to
4 whether these impacts disproportionately affect minority and low-income populations.
5

6 Changes in the operation of hydropower facilities and changes in hydropower costs could
7 affect environmental justice if any adverse impacts on health, environmental conditions,
8 economics, or Tribal values resulting from operational changes are determined to be high, and if
9 these impacts would disproportionately affect minority and low-income populations, including
10 impacts on Tribal groups. If the analysis determines that impacts on health, environmental
11 conditions, economics, and Tribal values are not significant, there can be no disproportionate
12 impacts on minority and low-income populations. In the event impacts are significant,
13 disproportionality would be determined by comparing the proximity of any high and adverse
14 impacts with the location of low-income and minority populations, including Tribal groups.
15

16 Although it is possible that there may be impacts on health, environmental conditions,
17 and Tribal values affecting low-income and minority populations, given the nature of proposed
18 changes in dam operations, it is likely that the most important impacts resulting from changes in
19 dam operations would be those on recreation in the area immediately surrounding Glen Canyon
20 and Grand Canyon. Accordingly, the analysis of environmental justice issues considered impacts
21 within the 11-county region in the vicinity of the lakes and river corridor, and in eastern Arizona
22 and northwestern New Mexico, which corresponds to the area in which the majority of impacts
23 on recreation of changes in dam operations would likely occur. A description of the geographic
24 distribution of minority and low-income groups in the affected area was based on demographic
25 data from the 2010 Census (U.S. Census Bureau 2013b) and the 2008–2012 American
26 Community Survey (U.S. Census Bureau 2013a). The following definitions were used to define
27 minority and low-income population groups:
28

- 29 • **Minority.** Persons are included in the minority category if they identify
30 themselves as belonging to any of the following racial groups: (1) Hispanic,
31 (2) Black (not of Hispanic origin) or African American, (3) American Indian
32 or Alaska Native, (4) Asian, or (5) Native Hawaiian or Other Pacific Islander.
33

34 Beginning with the 2000 Census, where appropriate, the census form allows
35 individuals to designate multiple population group categories to reflect their
36 ethnic or racial origin. In addition, persons who classify themselves as being
37 of multiple racial origins may choose up to six racial groups as the basis of
38 their racial origins. The term “minority” includes all persons, including those
39 classifying themselves in multiple racial categories, except those who
40 classify themselves as not of Hispanic origin and as White or Other Race
41 (U.S. Census Bureau 2013b).
42

- 43 • **Low-Income.** Individuals who fall below the poverty line. The poverty line
44 takes into account family size and age of individuals in the family. In 2013,
45 for example, the poverty line for a family of five with three children below
46 the age of 18 was \$27,400. For any given family below the poverty line, all

1 family members are considered as being below the poverty line for the
2 purposes of analysis (U.S. Census Bureau 2013b).

3
4 The CEQ guidance states that minority or low-income populations should be
5 identified where either (1) the minority or low-income population of the affected area
6 exceeds 50%, or (2) the minority or low-income population percentage of the affected
7 area is meaningfully greater than the minority population percentage in the general
8 population or other appropriate unit of geographic analysis. The environmental impact
9 statement applies both criteria in using the Census Bureau data for census block groups,
10 wherein consideration is given to the minority or low-income population in a census
11 block group where the relevant population is either 50% or more of the total block group
12 population, or where the relevant population is 20 percentage points higher than the state
13 average (the reference geographic unit) for the relevant population.

14
15 The data in Table 3.14-6 show the minority and low-income composition of the total
16 population located in the region, based on 2010 Census and 2008–2012 American Community
17 Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or Latino are
18 included in the table as a separate entry. However, because Hispanics can be of any race, this
19 number also includes individuals additionally identifying themselves as being part of one or
20 more of the population groups listed in the table.

21
22 A large number of minority and low-income individuals are located in the 11-county area
23 around the Glen Canyon and Grand Canyon. Within the area, 38.0% of the population is
24 classified as minority, while 12.7% is classified as low-income. The number of minority
25 individuals exceeds the state average by 20 percentage points or more in Apache County,
26 Arizona; McKinley County, New Mexico; and San Juan County, Utah; and exceeds 50% of the
27 total population in Apache County and Navajo County, Arizona; in Cibola County, McKinley
28 County, and San Juan County, New Mexico; and in San Juan County, Utah; meaning that there
29 are minority populations in each of these counties based on county-level data in the 2010 Census
30 and 2008–2012 American Community Survey data. As the number of low-income individuals
31 does not exceed the state average by more than 20 percentage points, or does not exceed 50% of
32 the total population in any of the 11 counties, there are no low-income populations based on
33 county level data in the 11-county region.

34
35 Within each county, there are block groups with minority and low-income populations.
36 Figures 3.14-1 and 3.14-2 show the locations of the minority and low-income population groups
37 in the 11-county area.

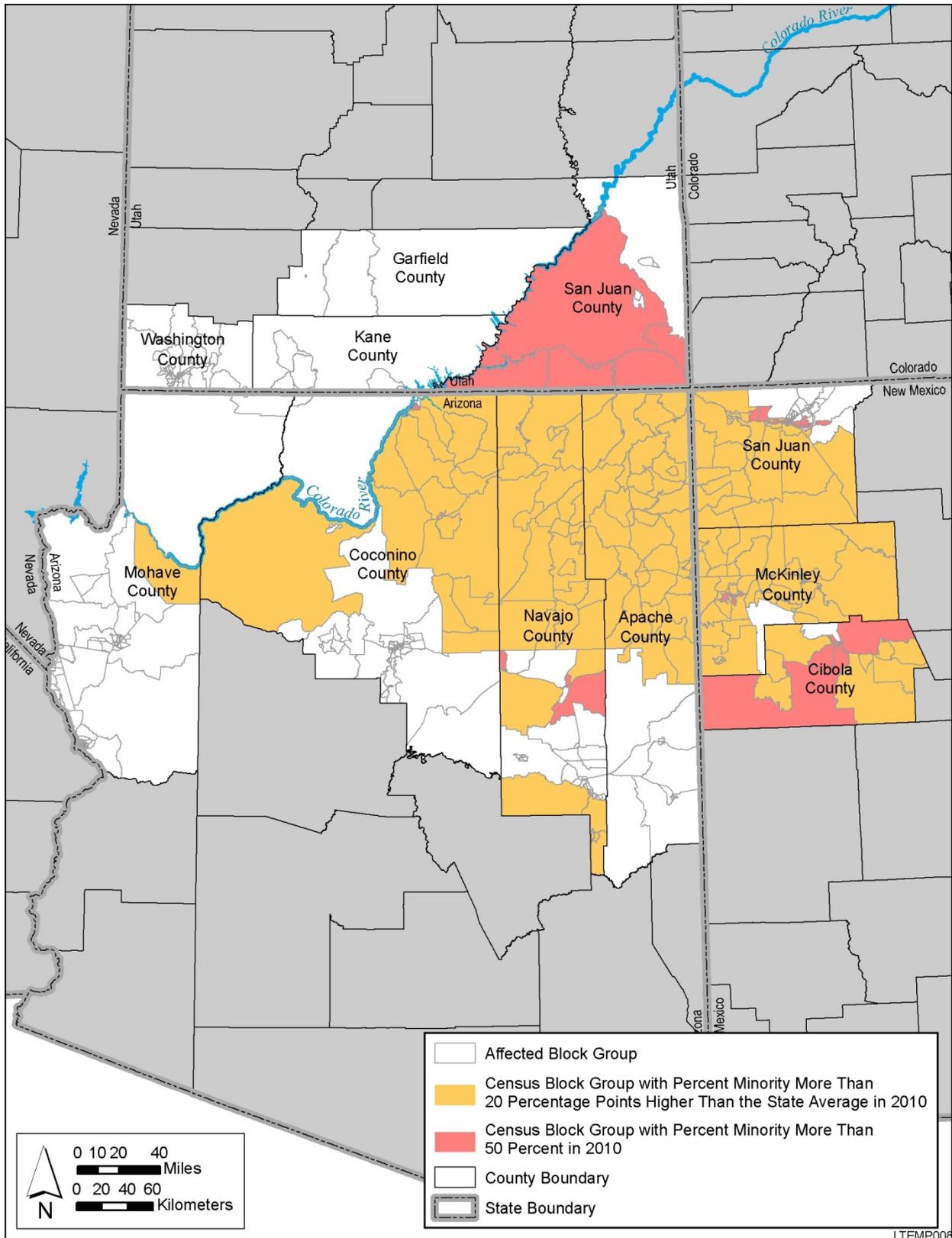
38
39 A large number of block groups in the 11-county area have populations whose percentage
40 of minority individuals is more than 20 percentage points higher than the state average. In the
41 Arizona counties, these block groups are located in the eastern part of Coconino County on the
42 Navajo Nation Indian Reservation and the Hopi Indian Reservation; in the western part of
43 Coconino County, which includes the Havasupai Indian Reservation and the Hualapai Indian
44 Reservation, which are also located in one block group in eastern Mohave County. The Navajo
45 Nation Indian Reservation and the Hopi Indian Reservation are also located in the central and
46 northern part of Apache County, which also contains the Fort Apache Indian Reservation in the

1 **TABLE 3.14-6 Minority and Low-Income Populations in the 11-County Area**

Population Type	Apache County, Arizona	Coconino County, Arizona	Mohave County, Arizona	Navajo County, Arizona	Cibola County, New Mexico	McKinley County, New Mexico	San Juan County, New Mexico	Garfield County, Utah	Kane County, Utah	San Juan County, Utah	Washington County, Utah	11-County Region
Total population	71,518	134,421	200,186	107,449	27,213	71,492	130,044	5,172	7,125	14,746	138,115	5,730,547
White, non-Hispanic	14,568	74,231	159,378	47,181	5,857	7,384	55,254	4,740	6,639	6,474	118,282	3,555,517
Hispanic or Latino	4,113	18,166	29,569	11,571	9,934	9,473	24,776	234	263	649	13,486	1,433,977
Non-Hispanic or Latino minorities	52,837	42,024	11,239	48,697	11,422	54,635	50,014	198	223	7,623	6,347	741,051
One race	51,753	39,222	7,985	47,047	11,077	53,329	47,564	161	153	7,371	4,161	646,795
Black or African American	157	1,495	1,715	842	221	317	617	13	15	21	632	67,458
American Indian or Alaskan Native	51,360	35,610	3,793	45,551	10,680	52,402	46,321	75	103	7,308	1,460	457,112
Asian	185	1,787	2,016	542	136	542	445	61	31	35	954	87,215
Native Hawaiian or other Pacific Islander	24	138	316	68	19	17	64	10	1	5	1,022	26,839
Some other race	27	192	145	44	21	51	117	2	3	2	93	8,171
Two or more races	1,087	2,802	3,254	1,650	345	1,306	2,450	37	70	252	2,186	94,256
Total minority	56,950	60,190	40,808	60,268	21,356	64,108	74,790	432	486	8,272	19,833	2,175,028
Low-income	19,838	23,050	37,426	24,061	6,468	19,985	20,576	628	539	4,103	20,225	729,333
Percent minority	76.9	44.8	20.4	56.1	78.5	89.7	57.5	8.4	6.8	56.1	14.4	38.0
State percent minority	42.2	42.2	42.2	42.2	59.5	59.5	59.5	19.6	19.6	19.6	19.6	–
Percent low-income	27.7	17.2	18.6	22.4	23.7	27.8	16.0	12.3	7.6	27.9	14.5	12.7
State percent low-income	12.4	12.4	12.4	12.4	14.9	14.9	14.9	12.1	12.1	12.1	12.1	–

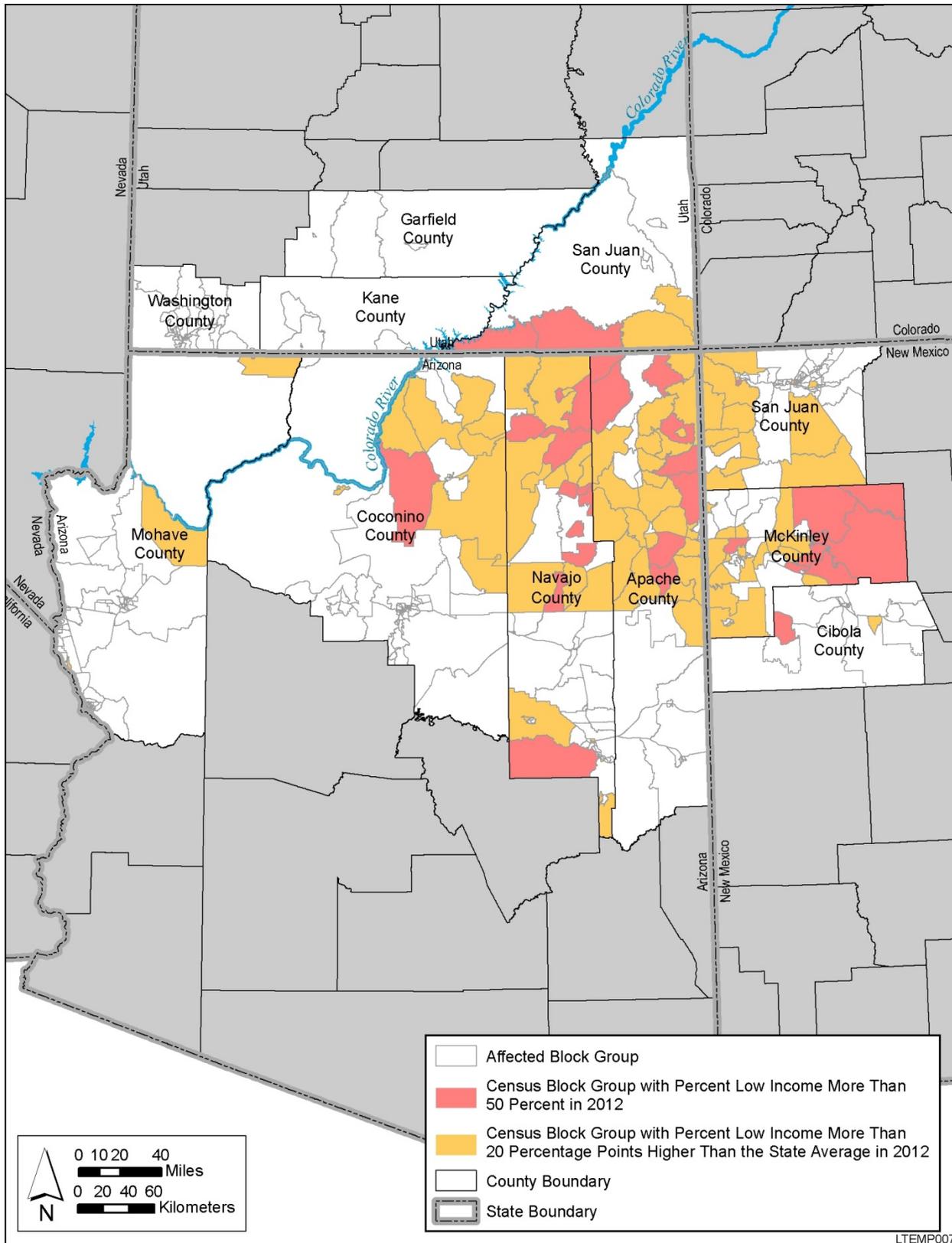
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1

2 **FIGURE 3.14-1 Minority Population Groups in the 11-County Area**



1

2 **FIGURE 3.14-2 Low-Income Population Groups in the 11-County Area**

1 southern part of the county. The Navajo Nation Indian Reservation is also located in the central
2 and northern part of Navajo County, Arizona, and in the western part of San Juan County, New
3 Mexico. In all census block groups in these areas, the number of minority individuals is higher
4 than the state average by 20 percentage points or more. Elsewhere in New Mexico, eastern San
5 Juan County, a large majority of McKinley County, which contains part of the Navajo Nation
6 Indian Reservation, part of the Zuni and Ramah Navajo Indian Reservations, and parts of Cibola
7 County, which contains parts of the Ramah Navajo Indian Reservations, the Acoma, Canoncito
8 and Laguna Indian Reservations, which all have block groups whose percentage of minorities is
9 more than 20 percentage points higher than the state average.

10
11 There are a number of census block groups in the 11-county area in which more than
12 50% of the total population is minority. These are located in the southern portion of San Juan
13 County, Utah, which includes the Navajo Nation Indian Reservation and the Ute Mountain
14 Indian Reservation; the western part of Cibola County, which includes the Zuni Indian
15 Reservation; and the eastern part of the Cibola County, which includes the Acoma, Canoncito
16 and Laguna Indian Reservations. Census block groups in Page, Winslow, and Holbrook,
17 Arizona, also have minority populations that are more than 50% of the total, as do census block
18 groups in, and in the vicinity of, Farmington and Shiprock, New Mexico

19
20 There are a large number of census block groups in the 11-county area in which the
21 percentage of low-income individuals is more than 20 percentage points higher than the state
22 average. These are located on the Navajo Nation Indian Reservation and the Hopi Indian
23 Reservation in Coconino County and on the Navajo Nation Indian Reservation in Navajo
24 County, Arizona, which also contains the Fort Apache Indian Reservation; and in Apache
25 County, Arizona, and San Juan County, New Mexico, on the Navajo Nation Indian Reservation.
26 There are also block groups in McKinley County, New Mexico, on the Zuni Indian Reservation
27 and in the vicinity of Gallup; in southeastern San Juan County, New Mexico; in eastern Mohave
28 County, Arizona, on the Hualapai Indian Reservation; in southeastern and southwestern San Juan
29 County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian
30 Reservation, where the percentage of low-income individuals is more than 20 percentage points
31 higher than the state average.

32
33 There are also a number of census block groups in the 11-county area in which more than
34 50% of the total population is below the poverty level. These are located in the eastern part of
35 Coconino County, Arizona, on the Navajo Nation Indian Reservation and Hopi Indian
36 Reservation; in southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation
37 and the Ute Mountain Indian Reservation; in the northern parts of Navajo County and Apache
38 County, Arizona; in southwestern Navajo County on the Fort Apache Indian Reservation; in
39 New Mexico, in the eastern part of McKinley County, in the vicinity of Gallup, and on the
40 Ramah Navajo Indian Reservation in Cibola County, New Mexico.

3.14.2 The Seven-State Region of Influence

This section describes current socioeconomic conditions within the seven-state region, the area in which electricity from Glen Canyon Dam is marketed, including Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming.

3.14.2.1 Population

Total population in the seven-state region was 21.9 million people in 2012, an increase from 17.7 million in 2000 (Table 3.14-7). Population in the region is concentrated in Arizona and Colorado, which, at 11.7 million people, had almost 54% of the total regional population in 2012.

Population in the seven-state study area grew at an annual average rate of 1.8% from 2000 to 2012. Growth within the region was uneven over the period, with higher than average annual growth rates in Nevada (2.7%), Arizona (2.1%), and Utah (2.1%). Growth rates in Colorado (1.6%) were closer to the average for the region, with lower than average rates in Wyoming (1.3%), New Mexico (1.1%), and Nebraska (0.7%).

The regional population is projected to reach 24.6 million in 2020 and 28.2 million 2030.

TABLE 3.14-7 Population in the Seven-State Region of Influence

State	2000	2012	Annual Growth Rate (%), 2000–2012	2020	2030
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Colorado	4,301,261	5,187,582	1.6	5,915,922	6,888,181
Nebraska	1,711,263	1,855,525	0.7	1,940,114	2,054,752
Nevada	1,998,257	2,798,931	2.7	2,959,641	3,222,107
New Mexico	1,819,046	2,085,538	1.1	2,351,724	2,613,332
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984
Wyoming	493,782	576,412	1.3	622,360	668,830
Total	17,687,410	21,872,530	1.8	24,583,995	28,214,986

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Colorado Department of Local Affairs (2013); Nebraska Department of Economic Development (2013); Nevada State Demographer’s Office (2013); University of New Mexico (2013); Governor’s Office of Planning and Budget (2013); Wyoming Department of Administration and Information (2013).

3.14.2.2 Income

Arizona and Colorado generated almost 55% of the income in the seven-state region, together producing almost \$469 billion in 2011 (Table 3.14-8). Personal income grew at an annual average rate of 2.0% over the period from 2000 to 2011, with higher than average growth rates in Wyoming (3.4%), New Mexico (2.5%), Utah (2.5%), and Arizona (2.3%). Income per capita rose slightly over the same period at a rate of 0.2%, resulting in an increase from \$38,640 to \$39,509. Per capita incomes were higher in 2011 in Wyoming (\$49,676), Colorado (\$45,628), and Nebraska (\$43,973) than the average for the region as a whole.

TABLE 3.14-8 Income in the Seven-State Region of Influence

State	2000	2011	Average Annual Growth Rate (%), 2000–2011
Arizona			
Income (billions of 2013\$)	183.6	235.4	2.3
Per-capita income (2013\$)	35,778	36,397	0.2
Colorado			
Income (billions of 2013\$)	198.9	233.4	1.5
Per-capita income (2013\$)	46,252	45,628	-0.1
Nebraska			
Income (billions of 2013\$)	66.3	81.0	1.8
Per-capita income (2013\$)	38,735	43,973	1.2
Nevada			
Income (billions of 2013\$)	84.6	104.3	1.9
Per-capita income (2013\$)	42,337	38,328	-0.9
New Mexico			
Income (billions of 2013\$)	56.0	73.6	2.5
Per-capita income (2013\$)	30,808	35,410	1.3
Utah			
Income (billions of 2013\$)	74.4	97.8	2.5
Per-capita income (2013\$)	33,333	34,738	0.4
Wyoming			
Income (billions of 2013\$)	19.6	28.2	3.4
Per-capita income (2013\$)	39,626	49,676	2.1
Total			
Income (billions of 2013\$)	683.4	853.7	2.0
Per-capita income (2013\$)	38,640	39,509	0.2

Source: U.S. Department of Commerce (2013).

1 Median household incomes (the income level at which exactly half of all households earn
 2 more than the level, and half earn less) over the period from 2008 to 2012 varied between
 3 \$45,542 in New Mexico and \$59,096 in Colorado (U.S. Census Bureau 2013a). Median
 4 household income in the United States was \$53,832 over the same period.

5
6
7 **3.14.2.3 Employment**

8
9 In 2012, more than 53% (5.3 million) of all employment in the seven-state power
 10 marketing service territory (9.9 million) was concentrated in Arizona and Colorado
 11 (Table 3.14-9). Employment in Utah was 1.3 million and 1.2 million in Nevada, the remaining
 12 states supporting 2.1 million jobs. Over the period from 2000 to 2012, annual employment
 13 growth rates were higher in Nevada (1.6%) and Utah (1.3%) than elsewhere in the seven-state
 14 study area, with rates in Colorado (0.8%), New Mexico (0.6%), and Nebraska (0.5%) lower than
 15 the average rate of 1.0%.

16
17
18 **TABLE 3.14-9 Employment in the Seven-State Region**
 19 **of Influence**

State	2000	2012	Average Annual Growth Rate (%), 2000–2012
Arizona	2,404,916	2,778,579	1.2
Colorado	2,300,192	2,523,535	0.8
Nebraska	923,198	980,668	0.5
Nevada	1,015,221	1,226,408	1.6
New Mexico	810,024	871,299	0.6
Utah	1,097,915	1,276,249	1.3
Wyoming	256,685	289,621	1.0
Total	8,808,151	9,946,359	1.0

Source: U.S. Department of Labor (2013).

20
21
22 In 2011, the service sector provided the highest percentage of employment in the
 23 seven-state region at almost 56%, followed by wholesale and retail trade (17.5%)
 24 (Table 3.14-10). Smaller employment shares were held by finance, insurance, and real estate
 25 (6.9%), and both construction and manufacturing (6.7%). Within the region, the distribution of
 26 employment across sectors varied somewhat compared to the region as a whole. Nebraska
 27 (5.7%) and Wyoming (4.6%) have a higher percentage of employment in agriculture than the
 28 region as a whole (2.2%), and these states have lower shares of employment in services
 29 compared with the region as a whole. Service sector employment in Nevada (62.9%) and
 30 Colorado (58.6%) is higher than in the region as a whole. Nebraska (10.8%) and Utah (10.2%)
 31

1 **TABLE 3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence^a**

Sector	Arizona		Colorado		Nebraska		Nevada	
	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture ^a	30,113	1.4	40,673	2.0	48,061	5.7	4,603	0.5
Mining	11,160	0.5	25,006	1.2	963	0.1	11,484	1.1
Construction	116,992	5.5	115,615	5.7	37,196	4.4	50,140	5.0
Manufacturing	137,532	6.4	117,810	5.9	91,190	10.8	39,277	3.9
Transportation and public utilities	87,613	4.1	68,901	3.4	38,583	4.6	48,147	4.8
Wholesale and retail trade	398,228	18.6	332,919	16.6	146,784	17.4	163,369	16.3
Finance, insurance, and real estate	168,747	7.9	132,273	6.6	68,097	8.1	57,788	5.7
Services	1,186,730	55.5	1,177,687	58.6	413,514	49.0	632,580	62.9
Other	175	0.0	375	0.0	60	0.0	175	0.0
Total	2,137,315		2,011,186		844,678		1,005,038	
Sector	New Mexico		Utah		Wyoming		Total	
	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture ^a	23,426	3.8	20,175	1.9	10,029	4.6	177,080	2.2
Mining	16,643	2.7	10,755	1.0	27,001	12.4	103,012	1.3
Construction	39,441	6.4	56,030	5.3	17,350	8.0	432,764	5.5
Manufacturing	27,434	4.4	106,865	10.2	9,644	4.4	529,752	6.7
Transportation and public utilities	21,385	3.4	50,294	4.8	13,861	6.4	328,784	4.2
Wholesale and retail trade	115,071	18.5	187,284	17.9	37,926	17.4	1,381,581	17.5
Finance, insurance, and real estate	31,848	5.1	76,448	7.3	10,925	5.0	546,126	6.9
Services	345,254	55.6	540,136	51.5	92,500	42.4	4,388,401	55.6
Other	62	0.0	60	0.0	75	0.0	982	0.0
Total	620,564		1,048,851		218,211		7,885,843	

^a Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

1 have larger than average shares of manufacturing sector employment, while mining is a more
 2 significant employer in Wyoming (12.4%) than elsewhere in the region.

3
 4
 5 **3.14.2.4 Unemployment**

6
 7 Between 2000 and 2011, average unemployment rates have varied across the seven-state
 8 region, from 7.7% in Nevada and 6.5% in Arizona to lower rates elsewhere in the region,
 9 particularly in Nebraska (3.8%) (Table 3.14-11). The average rate in the region over this period
 10 was 6.2%. Rates were higher in 2012 than average rates for the period from 2000 to 2011,
 11 unemployment standing at 11.1% in Nevada and 8.3% in Arizona, with lower rates in the other
 12 five states; the average rate for the region as a whole (7.6%) was also higher during this period
 13 than the corresponding average rate for 2000 to 2011.

14
 15
 16 **TABLE 3.14-11 Unemployment in the**
 17 **Seven-State Region of Influence^a**

State	Average Rate (%), 2000–2011	2012 (%)
Arizona	6.5	8.3
Colorado	6.0	8.0
Nebraska	3.8	3.9
Nevada	7.7	11.1
New Mexico	5.7	6.9
Utah	5.0	5.7
Wyoming	4.5	5.4
Total	6.2	7.6

Source: U.S. Department of Labor (2013).

18
 19
 20 **3.14.2.5 Environmental Justice**

21
 22 The data in Table 3.14-12 show the minority and low-income composition of total
 23 population located in the seven-state region based on 2010 Census and 2008–2012 American
 24 Community Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or
 25 Latino are included in the table as a separate entry. However, because Hispanics can be of any
 26 race, this number also includes individuals also identifying themselves as being part of one or
 27 more of the population groups listed in the table.

28
 29 A large number of minority and low-income individuals are located in the seven-state
 30 region in which electricity from Glen Canyon dam is marketed. In the region as whole, 35.7% of
 31 the population is classified as minority, while 15.1% is classified as low-income. However, the

1 **TABLE 3.14-12 State Minority and Low-Income Populations, 2010**

Category	Arizona	Colorado	Nebraska	Nevada	New Mexico	Utah	Wyoming	Region Total
Total population	6,392,017	5,029,196	1,826,341	2,700,551	2,059,179	2,763,885	563,626	21,334,795
White, Non-Hispanic	3,695,647	3,520,793	1,499,753	1,462,081	833,810	2,221,719	483,874	13,717,677
Hispanic or Latino	1,895,149	1,038,687	167,405	716,501	953,403	358,340	50,231	5,179,716
Non-Hispanic or Latino minorities	801,221	469,716	159,183	521,969	271,966	183,826	29,521	2,437,402
One race	686,590	368,869	130,757	442,837	242,131	134,841	21,216	2,027,241
Black or African American	239,101	188,778	80,959	208,058	35,462	25,951	4,351	782,660
American Indian or Alaska Native	257,426	31,244	14,797	23,536	175,368	27,081	11,784	541,236
Asian	170,509	135,564	31,919	191,047	26,305	54,176	4,279	613,799
Native Hawaiian or other Pacific Islander	10,959	5,661	966	15,456	1,246	23,909	365	58,562
Some other race	8,595	7,622	2,116	4,740	3,750	3,724	437	30,984
Two or more races	114,631	100,847	28,426	79,132	29,835	48,985	8,305	410,161
Total minority	2,696,370	1,508,403	326,588	1,238,470	1,225,369	542,166	79,752	7,617,118
Low-income	1,094,249	659,786	229,923	398,027	413,851	359,242	61,577	3,216,655
Percent minority	42.2	30.0	17.9	45.9	59.5	19.6	14.1	35.7
U.S. Percent	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3
Percent low-income	17.4	13.4	12.9	14.9	20.4	13.2	11.2	15.1
U.S. percent	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8

Sources: U.S. Census Bureau (2013a,b).

3-218

1 number of minority or low-income individuals does not exceed the respective national averages
2 by 20 percentage points or more, and does not exceed 50% of the total population in the area,
3 meaning that for the seven-state region as a whole, there are no minority or low-income
4 populations based on 2010 Census and 2008–2012 American Community Survey data. Within
5 one state in the region, New Mexico, 59.5% of the total population is minority, meaning that
6 according to 2010 Census and 2008–2012 American Community Survey data, there is a minority
7 population in the state.
8

9 Although there are no minority populations in any of the seven states, except for New
10 Mexico, and no low-income populations, there are a large number of Native American
11 individuals in the seven-state area, many of whom reside on Tribal Reservations. Section 3.9
12 provides more information on the location and Tribal population associated with Reservations.
13 Many of these individuals are low-income in status.
14

15 Tribal members receive a significant portion of their electricity from Western, which
16 currently targets an allocation of 65% of total Tribal electrical use to the 57 Tribes or Tribal
17 entities currently receiving an allocation of power from the SLCA/IP system, which includes
18 power from Glen Canyon Dam. Nine of these Tribes operate electric utilities and receive power
19 directly from Western, while the remaining 48 Tribes benefit from cheaper federal hydropower
20 through “benefit crediting” arrangements with SLCA/IP customers or other electric utilities.
21 Benefit credits are provided to a Tribe by the utility that serves the area in which the Tribe is
22 located in lieu of direct electric service by Western, and are intended to be the financial
23 equivalent of a direct allocation. Because the SLCA/IP rate is generally lower than the rate
24 charged for electrical power by the utility, the difference between the two rates is paid to each
25 Tribe by subtracting the amount of the benefit credit, pro-rated by the amount of electricity
26 consumed, from the monthly electric bill.
27

28 29 **3.15 AIR QUALITY** 30

31 Air quality is primarily affected by air emission sources, both natural (e.g., wildfires and
32 windblown dust) and man-made (e.g., power generation from fossil fuel–fired plants, such as the
33 nearby Navajo Generating Station, and potentially other plants in the 11-state area, as well as
34 onroad and offroad mobile sources such as vehicles).
35

36 Changes in operations at Glen Canyon Dam can create either more or less
37 hydroelectricity at certain times of the day to meet regional electricity demand. If less electricity
38 is available at Glen Canyon Dam, demand must be met by other means, which may include
39 powerplants fueled by fossil fuels (including coal, oil, and gas turbine plants) and nuclear, other
40 hydroelectric, wind, and solar energy sources, or by demand-side management. Changes in the
41 operation of Glen Canyon Dam, therefore, may indirectly affect air quality by potentially
42 changing the degree to which electricity demand is met within the region, with either non-
43 emission hydropower, wind, or solar powerplants, or emission-producing powerplants, such as
44 fossil fuel–fired powerplants that can directly affect air quality and related resources. These air
45 quality changes can also affect greenhouse gas (GHG) emissions that can influence climate

1 change. Local and regional GHG information is presented here, while climate change is
2 discussed in Section 3.16.

3 4 5 **3.15.1 Local Air Quality**

6
7 The Clean Air Act (CAA), as amended (42 USC 7401) established Prevention of
8 Significant Deterioration (PSD) provisions for use in protecting the nation's air quality and
9 visibility. The PSD provisions apply to new or modified major stationary sources and are
10 designed to keep an attainment area in continued compliance with the National Ambient Air
11 Quality Standards (NAAQS). Major stationary sources are industrial-type facilities and include
12 powerplants and manufacturing facilities that emit more than 100 tons per year of a regulated
13 pollutant. No major stationary sources are being proposed for construction or modification by the
14 proposed federal action; therefore the statutory provisions specific to PSD are not applicable.
15 However, there are criteria pollutants for which thresholds for increases in pollution
16 concentrations have been established. These include sulfur dioxide (SO₂), nitrogen dioxide
17 (NO₂), and particulate matter (PM), which are often analyzed. The PSD standards are most
18 stringent in Class I areas and are progressively less stringent in the Class II and Class III areas
19 (Table 3.15-1). GCNRA and LMNRA are designated as Class II areas, while GCNP is
20 designated as a Class I area.

21
22 Table 3.15-2 presents criteria pollutant and volatile organic compound (VOC) emission
23 totals in 2011 for Coconino and Mohave Counties (EPA 2013a), which encompass the GCNP.
24 The data represent 13 source categories (e.g., fuel combustion by power generation and industry,
25 highway vehicles, off-highway vehicles, and miscellaneous sources). Miscellaneous sources,
26 including prescribed/structural fires, wildfires, fugitive dust, and agricultural production, account
27 for a predominant portion of the two-county totals of PM with an aerodynamic diameter less than
28 or equal to 2.5 μm (PM_{2.5}), particulate matter with an aerodynamic diameter less than or equal to
29 10 μm (PM₁₀), and SO₂. In addition, miscellaneous sources are primary contributors to carbon
30 monoxide (CO) and VOC emissions, which account for more than 50% of their respective total
31 emissions. Highway vehicles are primary contributors to total NO_x emissions and secondary
32 contributors to total CO emissions. Off-highway vehicles are secondary contributors to total NO_x
33 and VOC emissions. In these counties, fuel combustion and industrial activities are minor
34 contributors to any criteria pollutant and VOC emissions.

35
36 Data on emissions from Tribal lands in Coconino and Mohave Counties are hard to find
37 because the emission data are given in total emissions for Tribal lands which straddle many
38 counties and even many states. One important point source within the area is the Navajo
39 Generating Station, a 2,250-MW coal-fired powerplant located on the Navajo Indian Reservation
40 near Page, Arizona (within Coconino County). NO_x emissions from this powerplant are about
41 three-fourths of the two-county emissions combined, while SO₂ emissions are much larger
42 (Table 3.15-2). There are three natural gas-fired powerplants in southwestern Mohave County
43 but none in Coconino County.

1 **TABLE 3.15-1 Clean Air Act Prevention of Significant Deterioration Designations**

Designation	Definition
Class I Area	Visibility is protected more stringently than under the NAAQS; includes national parks, wilderness areas, monuments, and other areas of special national and cultural significance.
Class II Area	Moderate change is allowed, but stringent air quality constraints are nevertheless desired.
Class III Area	Substantial industrial or other growth is allowed, and increases in concentration up to the national standards would be considered insignificant.

2
3
4
5
6

TABLE 3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand Canyon National Park and for the Navajo Generating Station, 2011

County/Facility	Annual Emissions (10 ³ tons) ^a					
	CO	NO _x	VOCs	PM _{2.5}	PM ₁₀	SO ₂
Coconino	117.41	14.24	26.17	8.98	17.76	0.67
Mohave	48.77	12.79	10.97	2.55	12.65	0.13
Two-county total	166.19	27.03	37.13	11.52	30.41	0.80
Navajo Generating Station ^b	1.96	19.84	0.03	2.83	4.11	4.64

^a CO = carbon monoxide; NO_x = nitrogen oxides; PM_{2.5} = particulate matter with an aerodynamic diameter of ≤ 2.5 μm; PM₁₀ = particulate matter with an aerodynamic diameter of ≤ 10 μm; SO₂ = sulfur dioxide; and VOC = volatile organic compound.

^b The 2,250-MW coal-fired powerplant is located on the Navajo Indian Reservation near Page, Arizona, which is within Coconino County. Emissions from the Navajo Generating Station are not included in Coconino County emission totals.

Source: EPA (2013a).

7
8
9
10

3.15.2 Regional Air Quality

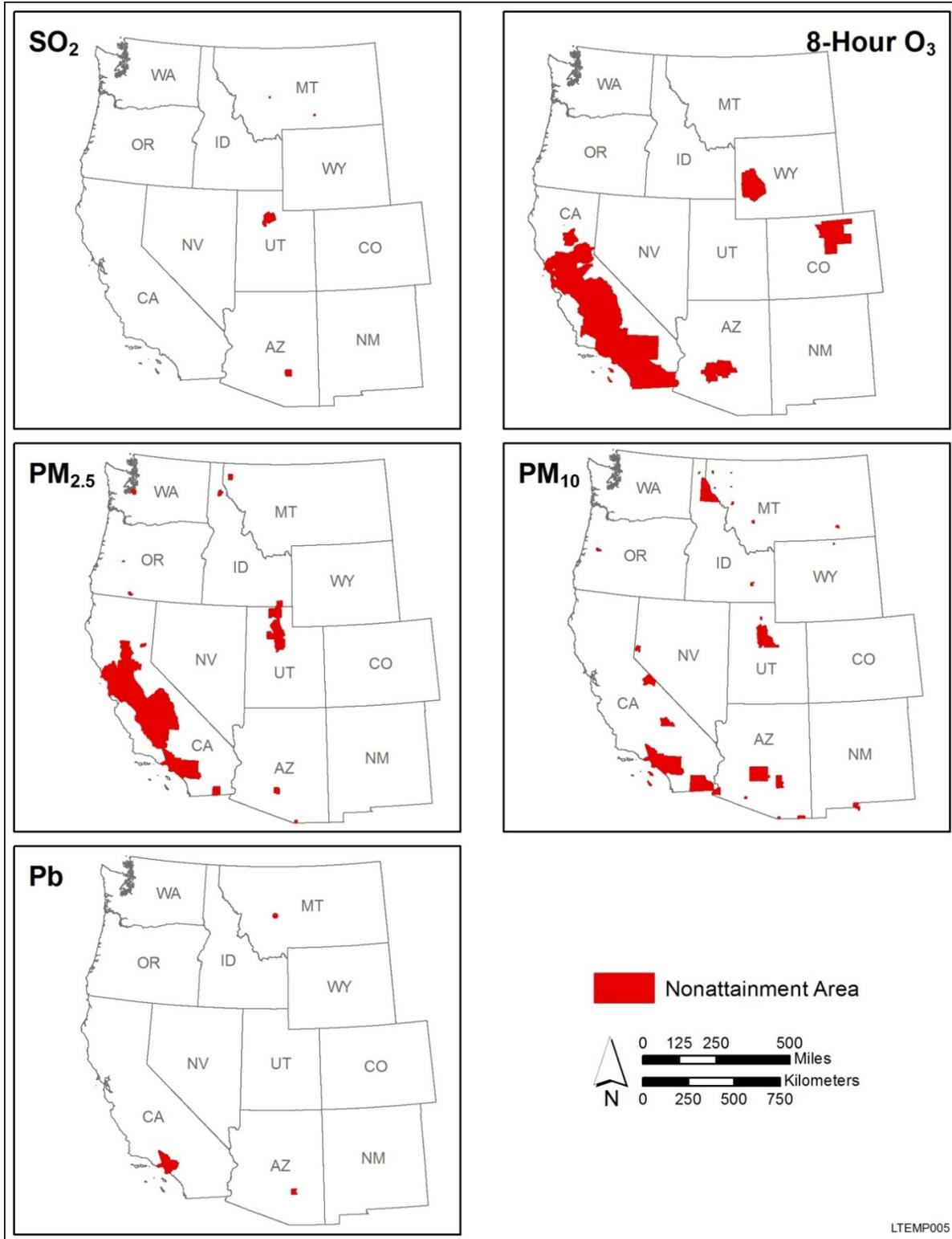
11 Changes in operations at Glen Canyon Dam can affect regional air quality if these
 12 changes result in corresponding increases or decreases in power generation at other facilities in
 13 the Western Interconnection grid. Under the CAA, the EPA has established the NAAQS for six
 14 criteria pollutants considered harmful to public health and the environment (40 CFR Part 50): SO₂,
 15 NO₂, CO, ozone (O₃), PM_{2.5}, PM₁₀, and lead (Pb) (EPA 2015a). Each state in this 11-state area
 16 can have its own State Ambient Air Quality Standards (SAAQS) for criteria pollutants. If a state
 17 has no standard corresponding to one of the NAAQS or a standard less stringent than NAAQS,
 18 the NAAQS apply. In addition, any state can establish standards for pollutants other than criteria
 19 pollutants. Several states have adopted standards for additional pollutants: visibility-reducing

1 particles, sulfates, hydrogen sulfide (H₂S), and vinyl chloride for California; fluorides for Idaho;
2 H₂S, settled PM, and fluoride in forage for Montana; H₂S for Nevada; total suspended
3 particulates, H₂S, and total reduced sulfur for New Mexico; particle fallout for Oregon;
4 radionuclides and fluorides for Washington; and H₂S, suspended sulfates, fluorides, and odors
5 for Wyoming.

6
7 Parts of the 11-state area have not yet attained the NAAQS for SO₂, 8-hour O₃, PM_{2.5},
8 PM₁₀, and Pb, as shown in Figure 3.15-1 (EPA 2015b). Currently, there are no nonattainment
9 areas for NO₂ and CO in the United States, and thus in the 11-state area. Except for Washington,
10 each state has one or more nonattainment areas. Arizona has nonattainment areas for all five air
11 pollutants, while California and Montana have nonattainment areas for four air pollutants. In
12 contrast, Washington has no nonattainment areas. Utah has nonattainment areas for three air
13 pollutants. Three states (Idaho, Oregon, and Wyoming) have nonattainment areas for two air
14 pollutants, while three states (Colorado, Nevada, and New Mexico) have nonattainment areas for
15 one air pollutant. Nonattainment areas are mostly located in urban areas, except for the rural
16 environment of the Upper Green River Basin in southwestern Wyoming, due to high wintertime
17 ozone.

18
19 There are many regional air pollution problems such as O₃, acid deposition, and visibility
20 degradation in the western United States. Ozone issues are most prevalent around urban centers,
21 with the exception of elevated wintertime O₃ at higher elevations near oil and gas fields in Utah,
22 Wyoming, and Colorado, where snow cover is prevalent. Impacts of acid deposition have been
23 observed in the Desert Southwest, where excess nitrogen deposition facilitates invasion of
24 nonnative grass species that compete with native plant species and increase fire risk due to
25 increased biomass fuel loading. Acid deposition may also affect high-elevation lakes where
26 excess nitrogen deposition can alter aquatic species composition. Visibility impairment is a
27 widespread and pervasive problem throughout the country, and, in particular, in many national
28 parks and wilderness areas where the CAA specifically requires visibility protection.

29
30 Visibility degradation is caused by cumulative emissions of air pollutants from a myriad
31 of sources scattered over a wide geographical area. In general, the primary cause of visibility
32 degradation is the scattering and absorption of light by fine particles, with a secondary
33 contribution provided by gases. In general, visibility conditions in the western United States are
34 substantially better than those in the eastern United States because of the higher pollutant loads
35 and humidity levels in the East (EPA 2006). The typical visual range (defined as the farthest
36 distance at which a large black object can be seen and recognized against the background sky) in
37 most of the western United States is about 60 to 90 mi, while that in most of the eastern
38 United States is about 15 to 30 mi. Most visibility degradation is associated with combustion-
39 related sources, while fugitive dust sources contribute to some extent. In particular, smaller
40 particles such as PM_{2.5} scatter light more efficiently, which includes ammonium sulfate,
41 ammonium nitrate, particulate organic matter, light-absorbing carbon (or soot), mineral fine soil,
42 and sea salt. Ammonium sulfate and ammonium nitrate are formed by chemical reactions in the
43 atmosphere that include emissions of SO₂ and NO_x, respectively. Particulate organic matter
44 (POM) can be emitted directly from vegetation or can form in the atmosphere from a variety of
45 gaseous organic compounds. At the GCNP, POM has the greatest impact on visibility, followed
46 by ammonium sulfate (Hand et al. 2011).



1

2

3

4

FIGURE 3.15-1 Nonattainment Areas for SO₂, 8-Hour O₃, PM_{2.5}, PM₁₀, and Pb in the 11-State Area (Note that currently there are no nonattainment areas for NO₂ and CO in the United States and thus in the 11-state area.) (Source: EPA 2015b)

1 Visibility was singled out for particular emphasis in the CAA Amendments (CAAA) of
2 1977. Visibility in a Class I area is protected under two sections of the CAAA. Section 165
3 provides for the PSD program (described in Section 3.15.2) for new sources. Section 169(A), for
4 older sources, describes requirements for both reasonably attributable single sources and regional
5 haze, which address multiple sources. Federal land managers have a particular responsibility to
6 protect visibility in Class I areas. There are 158 mandatory federal Class I areas in the
7 United States, and those in the 11-state area are illustrated in Figure 3.15-2 (EPA 2013b).

8
9 In 1999, the EPA issued the final Regional Haze Rule (64 FR 35714, July 1, 1999) which
10 sets a national visibility goal for preventing future and remedying existing impairment to
11 visibility in Class I areas. The rule is designed to reduce visibility impairment from existing
12 sources and limit visibility impairment from new sources. States with Class I areas or states
13 affecting visibility in Class I areas must revise their state implementation plans, prepare
14 emission-reduction strategies to reduce regional haze, and establish glide paths for each Class I
15 area. States are required to periodically review whether they are making reasonable progress
16 toward meeting the goal of achieving natural conditions by 2064. Wildfires and windblown dust
17 storms can significantly degrade visibility at Class I areas in the 11-state area. Emissions of SO₂
18 and NO_x from fossil fuel combustion are the major man-made causes of visibility impairment;
19 these emissions have been substantially reduced in the 11-state area in the past decade in
20 response to state and federal requirements (ARS 2013).

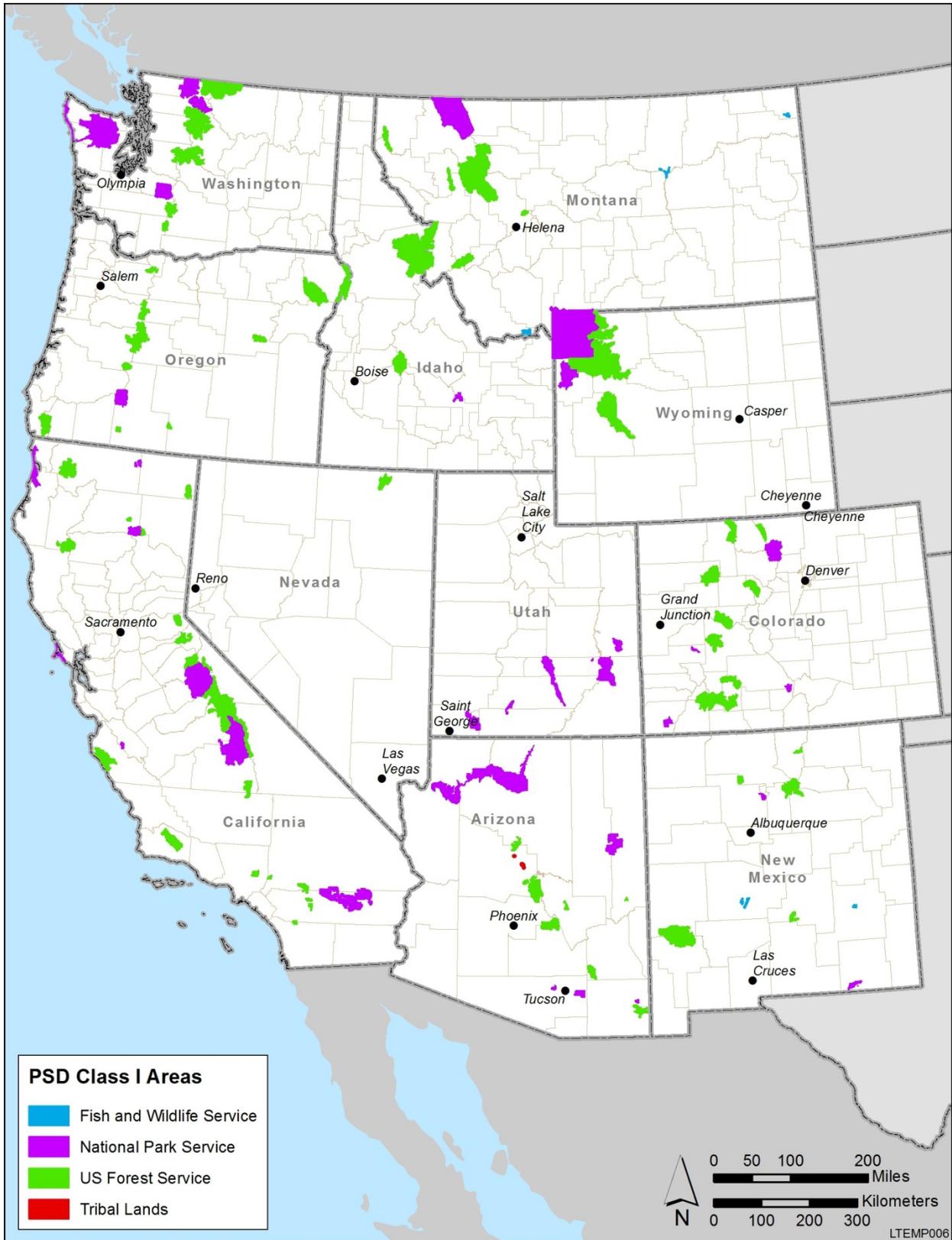
21 22 23 **3.15.3 Regional Air Emissions**

24
25 Table 3.15-3 presents statewide criteria pollutants and VOC emissions for the 11-state
26 area within the Western Interconnect in 2011 (EPA 2013a). As discussed in Section 3.15.2,
27 emission data are given in 13 source categories. Overall, miscellaneous sources are primary
28 contributors to CO, PM_{2.5}, PM₁₀, and VOCs for the 11-state totals. Highway vehicles and fuel
29 combustion for electricity generation are primary contributors to NO_x and SO₂, which account
30 for about 45% and 41% of the 11-state total emissions, respectively. Among the 11 states in the
31 region, all criteria pollutants and VOC emissions, except PM₁₀ and SO₂, are highest in
32 California. PM₁₀ emissions are highest in New Mexico. SO₂ emissions are highest in Wyoming,
33 which burns large quantities of fossil fuel (notably coal) for power generation and industrial
34 activities. Total criteria pollutant and VOC emissions combined are highest in California
35 followed by Arizona, and lowest in Nevada.

36
37 Table 3.15-3 also shows total statewide gross¹⁰ GHG emissions on a consumption basis
38 in terms of carbon dioxide equivalent (CO₂e).¹¹ GHG emissions for California are the highest at
39 453.1 million metric tons (MMt) (499.5 million tons) CO₂e, followed by Colorado, while those

¹⁰ Excluding GHG emissions removed due to forestry and other land uses.

¹¹ The carbon dioxide equivalent is a measure used to compare the emissions from various GHGs on the basis of their global warming potential (GWP), which is defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO₂ over a specific time period. For example, GWP is 21 for CH₄, 310 for N₂O, and 23,900 for SF₆. Accordingly, CO₂e emissions are estimated by multiplying the mass of a gas by the GWP.



1

2 **FIGURE 3.15-2 PSD Class I Areas in the 11-State Affected Area (Source: EPA 2013b)**

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TABLE 3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010, over the 11-State Affected Area within the Western Interconnect

State	Annual Emissions (10 ³ tons; million metric tons for CO ₂ e) ^a						
	CO	NO _x	VOCs	PM _{2.5}	PM ₁₀	SO ₂	CO ₂ e ^b
Arizona	2,357	251	508	178	405	77	116.6
California	3,674	736	836	208	475	36	453.1
Colorado	1,340	282	500	103	332	57	129.3
Idaho	1,111	98	258	116	431	14	39.6
Montana	1,321	119	342	141	437	29	38.5
Nevada	509	99	87	37	169	13	58.1
New Mexico	1,392	208	440	180	916	30	77.5
Oregon	2,285	161	495	183	372	30	74.7
Utah	595	185	241	39	184	28	75.7
Washington	1,648	278	307	92	249	30	103.0
Wyoming	1,106	196	296	130	483	80	60.3
11-State Total	17,338	2,614	4,311	1,407	4,454	425	1,226.4

^a CO = carbon monoxide; CO₂e = carbon dioxide equivalent; NO_x = nitrogen oxides; PM_{2.5} = particulate matter with an aerodynamic diameter of ≤2.5 μm; PM₁₀ = particulate matter with an aerodynamic diameter of ≤10 μm; SO₂ = sulfur dioxide; and VOC = volatile organic compound.

^b Total gross emissions on the consumption basis. To convert from metric ton to ton, multiply by 1.1023.

Sources: ADEQ (2006b); ARB (2014); Bailie et al. (2006), Bailie, Roe et al. (2007); Bailie, Strait et al. (2007); CCS (2007); EPA (2013a); NDEP (2008); ODEQ, ODOE, and ODOT (2013); Roe et al. (2007); Strait et al. (2007, 2008).

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for Montana are the lowest at 38.5 MMt (42.4 million tons) CO₂e. Wyoming also produces a relatively large amount of CO₂e, but about one-third of the state's CO₂e emissions result from the production of electricity that is exported out of state. Total emissions from the 11-state area are about 1,226.4 MMt (1,351.9 million tons) CO₂e. This equates to about 18.0% of total GHG emissions in the United States during 2010, at 6,810.3 MMt (7,507.0 million tons) CO₂e (EPA 2013c).

3.16 CLIMATE CHANGE

Climate change may affect resources that are also affected by LTEMP alternatives. As explained in the air quality discussion (Section 3.15), changes in operations at Glen Canyon Dam have the potential to alter emissions from other sources of electricity, sources that can produce more GHGs than hydroelectric power. Climate change is also predicted to affect climate and hydrology in the region, which could affect resources in the project area.

1 As discussed above, dam operations can affect air quality including the concentration of
2 GHGs in the atmosphere. GHGs are transparent to incoming short-wave radiation from the sun
3 but opaque to outgoing long-wave (infrared) radiation from the earth's surface. The net effect
4 over time is a trapping of absorbed radiation and a tendency to warm the earth's atmosphere,
5 which together constitute the "greenhouse effect." The principal GHGs that enter the atmosphere
6 due to human activities, including fossil fuel power generation, include carbon dioxide (CO₂),
7 methane (CH₄), nitrous oxide (N₂O), and fluorinated gases such as hydrofluorocarbons (HFCs),
8 perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). Some GHGs such as CO₂, CH₄, and
9 N₂O occur naturally and are emitted to the atmosphere through natural processes as well.

10
11 In the arid/semiarid western states, climate change is already having serious
12 consequences on the region's scarce water supplies; this particularly applies to the snow that
13 makes up most of the region's precipitation and that, when melted, provides 70% of its water. To
14 date, decreases in snowpack, less snowfall, earlier snowmelt, more winter rain events, increased
15 peak winter flows, and reduced summer flows have been documented (Saunders et al. 2008).
16 Another potential effect of climate change is that more dust will be produced as vegetative cover
17 decreases and as soils become dry (Mormon 2010). It is widely understood that impurities in
18 snow, such as dust or soot, decrease snow albedo¹² and enhance solar radiation absorption and
19 melt rates. Dust may shorten snow-cover duration by as much as a month (Painter et al. 2007).
20 Earlier spring snowmelt and higher spring/summer temperatures have broad implications with
21 regard to water resources in southwestern states that are already strapped for water, especially
22 during the summer when peak demand is higher, and these factors also lead to increased numbers
23 of forest fires (USGCRP 2014). It is likely that most dust on snowpack at high mountains is
24 coming both from nearby lands where soil-disturbing activity has made the land susceptible to
25 wind erosion and dust from the deserts of Colorado Plateau along with prevailing westerlies, and
26 to dust from other southwestern deserts to some extent. Activities such as exploration and
27 development of energy resources, offroad vehicle use, agriculture, and grazing serve to
28 destabilize soils, making them more susceptible to wind erosion (Belnap et al. 2009).

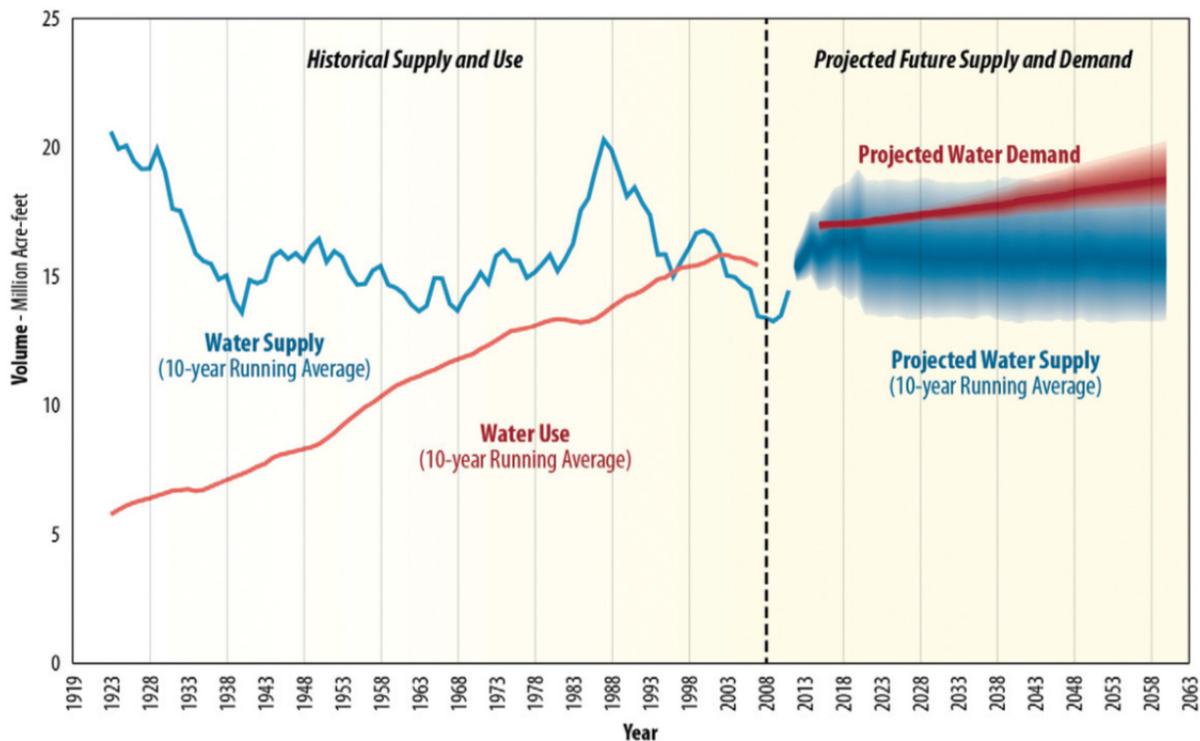
29
30 In December 2012, the Bureau of Reclamation and agencies representing the seven
31 Colorado River Basin States completed the Colorado River Basin Water Supply and Demand
32 Study (Reclamation 2012e). The purpose of the Study was to define future imbalances in water
33 supply and demand in the Basin through the year 2060, and to develop and analyze options and
34 strategies to resolve those imbalances. The study used several different scenarios for both supply
35 and demand to capture a range in potential future conditions. The supply conditions included the
36 downscaled general circulation model (GCM) projected trends and variability (downscaled
37 GCM) scenario. This scenario was developed as one plausible projection of the future based on
38 recent studies of future changes in climate variability and climate trends, and their influence on
39 streamflow and Basin water supply, which indicate that the climate will continue to warm, and
40 that there will be corresponding changes in regional precipitation and temperature trends beyond
41 what has occurred historically. Comparing the median of the water supply projections against the

¹² The fraction of solar radiation reflected from an object or surface, often expressed as a percentage.

1 median of the water demand projections, the long-term projected imbalance in future supply and
 2 demand is about 3.2 million ac-ft by 2060 (Figure 3.16-1).
 3

4 Another key Reclamation document that provides information regarding climate change
 5 is the 2011 SECURE Water Act Report (Reclamation 2011e). It identifies climate challenges the
 6 Colorado River Basin could likely face:
 7

- 8 • On average, Colorado River Basin temperature is projected to increase by
 9 5 to 6°F during the 21st century, with slightly larger increases projected in the
 10 upper Colorado Basin.
- 11 • Precipitation is projected to increase by 2.1% in the upper basin while
 12 declining by 1.6% in the lower basin by 2050.
- 13 • Mean annual runoff is projected to decrease by 3.5 to 8.5% by 2050.
- 14 • Warmer conditions will likely transition snowfall to rainfall, producing more
 15 December to March runoff and less April to July runoff.
- 16
- 17
- 18
- 19
- 20



21
 22 **FIGURE 3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water**
 23 **Supply and Demand (medians of projections are indicated by the darker shading)**
 24 **(Source: Reclamation 2012e)**
 25

1 Historical and projected climate changes have potential impacts for the basin:
2

- 3 • Spring and early summer runoff reductions could translate to a drop in water
4 supply for meeting irrigation demands, resulting in lower reservoir levels,
5 which adversely impacts energy production from hydropower operations at
6 the Glen Canyon and Hoover Dams.
7
- 8 • Increased winter runoff may require infrastructure modification or flood
9 control rule changes to preserve flood protection, which could further reduce
10 warm-season water supplies.
11
- 12 • Warmer conditions might cause changes in fisheries habitat, shifts in species
13 geographic ranges, increased water demands for instream ecosystems and
14 thermoelectric power production, increased power demands for municipal
15 uses (including cooling) and increased likelihood of invasive species
16 infestations. Endangered species issues might be exacerbated.
17

18 The extent to which climate change could affect future water supply is considered in the
19 hydrology modeling for the proposed action and all alternatives. See Section 3.2.1 for an
20 explanation of the methodology for hydrology modeling.
21

22 Although no studies specifically evaluate the potential effects of climate change on Lake
23 Powell or the Colorado River between Lake Powell and Lake Mead, decreases in Lake Powell
24 elevation and corresponding increases in temperatures of water releases from Glen Canyon Dam
25 and in water temperature of the Colorado River downstream (as well as to tributaries of the
26 Colorado River) are important potential effects of climate change on the project area. Projections
27 of future supply and demand in the basin indicate that inflows into Lake Powell may decrease,
28 and the effect of climate change is likely to exacerbate this effect (Reclamation 2012e). Increases
29 in the water temperature of Colorado River mainstem and its tributaries in Grand Canyon due to
30 climate change could expand the distribution of warm water-adapted nonnative fishes (Eaton and
31 Scheller 1996; Rahel and Olden 2008), which can prey on and compete with native fishes such
32 as endangered humpback chub or disadvantaged coldwater nonnative species. Climate-change-
33 driven warmer water temperatures across the contiguous United States are predicted to expand
34 the distribution of existing aquatic nonnative species by providing 31% more suitable habitat for
35 aquatic nonnative species, based upon studies that compared the thermal tolerances of 57 fish
36 species with predictions made from climate change temperature models (Mohseni et al. 2003).
37 Climate change also may facilitate expansion of nonnative parasites such as Asian tapeworm
38 (Rahel et al. 2008), another threat to native fishes such as humpback chub. Cold water
39 temperatures in the mainstem Colorado River in Marble and Grand Canyons have so far
40 prevented these warm water fishes and parasites from expanding their distribution in the project
41 area. Warmer climate trends could result in warmer overall water temperatures, increasing the
42 prevalence of these species and threatening native fish populations.
43

44 Climate change effects on Lake Powell's elevation could also affect the amount of
45 electric energy produced by the Glen Canyon Dam Powerplant over the study period, as well as
46 the electric capacity of the Glen Canyon Dam. The hydraulic head (water pressure) on the

1 turbines in the Glen Canyon Dam Powerplant is directly proportional to the elevation in Lake
2 Powell. Thus, when Lake Powell's elevation drops, the amount of hydropower generated by a
3 given release volume also decreases. Ultimately, if Lake Powell drops low enough, no power can
4 be produced at Glen Canyon Dam (at a Lake Powell elevation of 3,490 ft).
5

6 In addition to water temperature, other aspects of water quality are also affected by Lake
7 Powell's elevation. Dissolved oxygen concentrations in the tailwater are usually slightly below
8 saturation but have not dropped to concentrations low enough to affect the aquatic ecosystem in
9 Grand Canyon. However, climate-change driven decreases in the elevation of Lake Powell could
10 increase the chances of water that is low in DO being released from Glen Canyon Dam
11 (Vernieu et al. 2005). Low DO in the tailwater could adversely affect the rainbow trout fishery
12 Glen Canyon. Similarly, an increase in water temperatures of the Colorado River driven by
13 climate change could cause low levels of DO in Lake Mead that could adversely affect native
14 and nonnative fish (Tietjen 2014).
15

16 Climate change could have mixed effects on sediment supply and retention in the
17 Colorado River in the project area. For example, reduced precipitation under climate change
18 could lower sediment input from tributaries to the mainstem of the Colorado River. In addition,
19 higher variability in flows under climate change may require higher flows in equalization years,
20 which could lead to a large erosive effect. Conversely, lower average flows in the Colorado
21 River could positively affect overall sediment retention.
22
23

4 ENVIRONMENTAL CONSEQUENCES

This chapter presents the comparative analysis of the environmental effects of the Long-Term Experimental and Management Plan (LTEMP) alternatives described in Chapter 2. Environmental effects are analyzed for resources that could be affected by the proposed action, to adopt and implement an LTEMP for Glen Canyon Dam over the next 20 years. The affected resources are described in Chapter 3. Affected natural resources include water, sediment, aquatic ecology, vegetation, wildlife, special status species, and air quality. Affected socioeconomic resources include cultural resources, visual resources, recreational resources, wilderness, park management and operations, hydropower, regional socioeconomics, resources of importance to Indian Tribes, and environmental justice.

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 restoration activities, which would be undertaken as part of the alternative.

In the following sections, the effects of the alternatives are presented for each resource. Discussions begin with an identification of the resource issues being analyzed and a description of the indicators that are evaluated to assess the related issues. The analysis methodology is presented next, describing both the quantitative and qualitative methods used to assess effects. A summary of effects follows, focusing on the general effects of various flow conditions on resource indicators. An alternative-specific analysis is then presented wherein the effects of the various alternatives are presented individually and compared. Finally, in Section 4.17, an analysis is presented of the cumulative impacts of the alternatives on resources in combination with other past, present, and reasonably foreseeable future actions.

4.1 OVERALL ANALYSIS AND ASSESSMENT APPROACH

The quantitative analyses in this chapter employ a series of linked models that explicitly account for flow effects and the linkages among resources. The discussion of effects by resource acknowledges these linkages under a common conceptual model. This conceptual model is central to the construction of the LTEMP alternatives described in Chapter 2. The modeling approach used for this Draft Environmental Impact Statement (DEIS) is presented in technical appendices provided at the end of this document.

Six action alternatives are compared to the No Action Alternative (Alternative A), which describes how the dam is currently operated. Operations under Alternative A employ a release pattern established in the 1996 Record of Decision (ROD) (Reclamation 1996) associated with

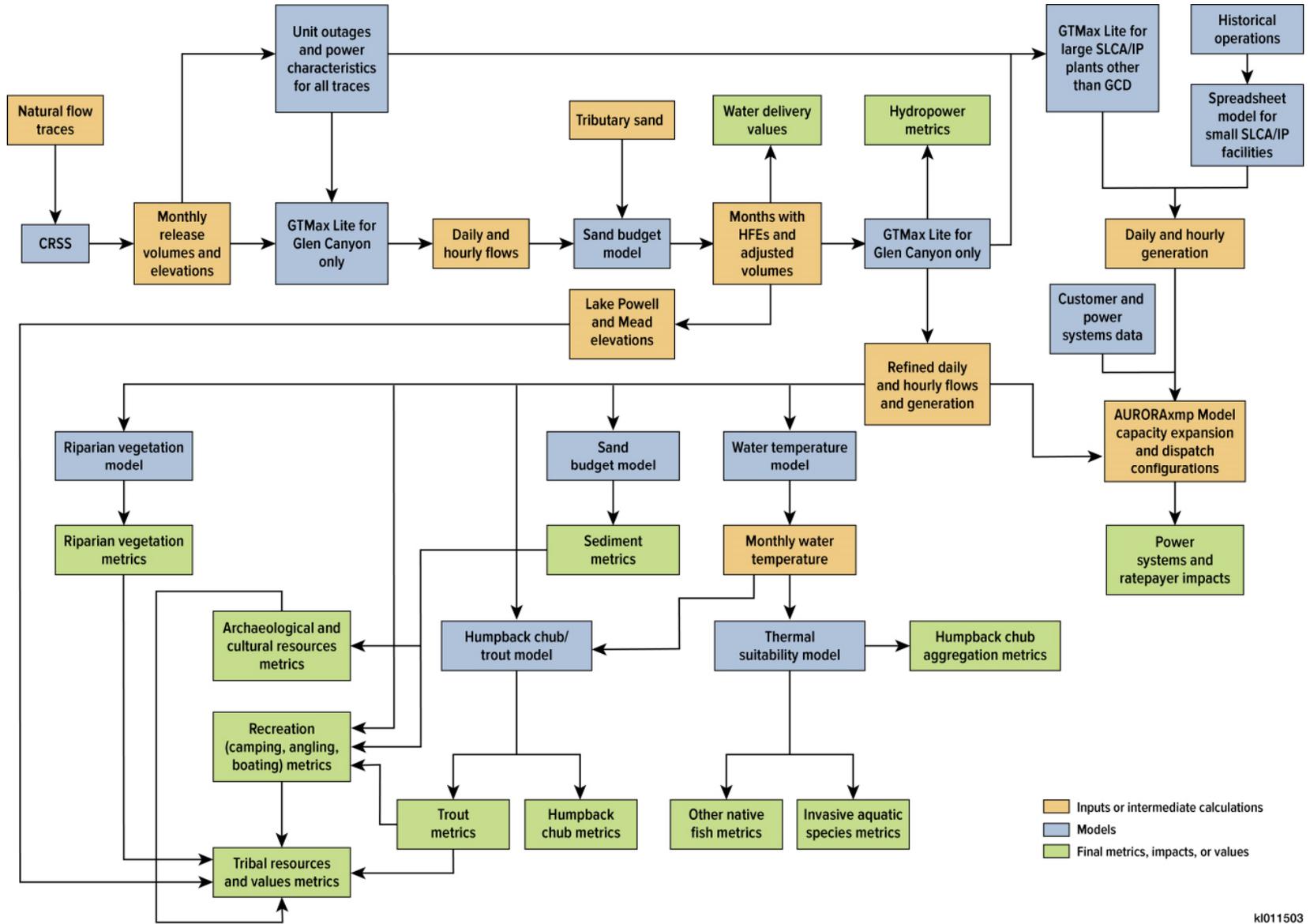
1 the 1995 EIS on operations of Glen Canyon Dam (Reclamation 1995). This operational release
2 pattern, referred to as Modified Low Fluctuating Flows (MLFF), moderated the releases relative
3 to operations practiced in the 1960s through 1980s. As described in Chapter 2, Alternative A also
4 includes various practices and operational decisions that have been established since the
5 1996 ROD.

6
7 Operational characteristics and experimental actions of each alternative target particular
8 resource effects. Environmental effects caused by actions included in different alternatives were
9 modeled using historically observed resource responses to flow conditions and relationships
10 derived from experimental results obtained since dam operations were last reviewed in 1995.

11
12 Responses of resources to operations and non-flow actions were predicted using linked
13 models (e.g., reservoir operations model, hydropower operations models, sand budget model,
14 and others, as depicted in Figure 4-1). The magnitude of effects was estimated using quantifiable
15 metrics for indicators of the condition of a resource. The environmental effects of alternatives are
16 compared quantitatively whenever possible, on the basis of the estimated effect on resource
17 condition as measured by a set of resource metrics (see Appendix B for details); these
18 quantitative predictions are supported when possible by published observations and findings.

19
20 We used a Structured Decision Analysis approach as the basis for our modeling
21 framework (see Appendix C for a full description). Because several of the alternatives use a
22 condition or information-dependent approach to experimentation that would adapt to new
23 information gathered as the alternative is implemented (e.g., Alternatives B, C, D, and E), we
24 developed a set of “long-term strategies” that represented possible ways the alternative might be
25 implemented if uncertainties were resolved. With this approach, we established versions of these
26 alternatives (the long-term strategies) that implemented subsets of the proposed experiments
27 being considered in the alternative. Because there are many possible combinations of
28 experiments possible within any alternative, we chose sets that would be representative of certain
29 conditions related to uncertainties; there were 19 of these (Table 4.1-1). For example, if under
30 Alternative D the effect of trout on humpback chub was determined to be more important than
31 temperature, and trout management flows (TMFs) proved to be effective at controlling trout
32 numbers, a long-term strategy that included spring and fall high-flow experiments (HFEs) and
33 TMFs would be implemented. Under this scenario, there would be no need for low summer
34 flows to warm water for chub. Long-term strategy D4 represents this scenario.

35
36 To facilitate comparisons of alternatives in the text, we chose a single-long-term strategy
37 for each alternative—A, B1, C1, D4, E1, F, and G. Long-term strategies C1, D4, and E1 were
38 chosen because they included a comparable set of experimental elements (spring and fall HFEs
39 and TMFs). Long-term strategy B1 was chosen because it did not include hydropower
40 improvement flows, and was thus comparable to other long-term strategies. The analytical results
41 for the full suite of long-term strategies enabled a determination of the effects of experiments,
42 and these effects are described in the individual resource sections of this chapter. The
43 quantitative results for all 19 long-term strategies are presented in Appendix C and the resource-
44 specific Appendices E, F, G, H, I, and J.



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FIGURE 4-1 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output

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1 **TABLE 4.1-1 Experimental Elements Included in Long-Term Strategies Associated with Each LTEMP Alternative (Letters depict**
 2 **alternative, numbers depict long-term strategy.)**

Experimental Element	Alternative and Associated Long-Term Strategy ^a																		
	A	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F	G
Spring HFE	Y ^b	Y ^c	Y ^c	Y	Y	N	N	Y ^d	Y ^d	Y ^d	Y ^d	Y ^e	Y ^e	N	N	N	N	Y	Y
Fall HFE	Y ^b	Y ^c	Y ^c	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y
Spring proactive HFE	N	N	N	Y ^f	Y ^f	N	N	Y ^f	Y ^f	Y ^f	Y ^f	N	N	N	N	N	N	N	Y ^f
Extended- duration HFE	N	N	N	Y ^g	Y ^g	N	Y ^g	Y ^h	Y ^h	Y ^h	Y ^h	N	N	N	N	N	N	N	Y ⁱ
Load-following curtailment (steady flows)	N	N	N	Y ^j	Y ^j	N	Y ^j	Y ^k	Y ^k	Y ^k	Y ^k	Y ^l	Y ^l	N	Y ^l	N	N	N	N
Low summer flows	N	N	N	N	Y ^m	N	N	Y ⁿ	Y ⁿ	Y ⁿ	N	N	Y	N	N	Y	N	N	N
Steady weekend flows for macroinvertebrate production	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
Mechanical trout removal	Y ^b	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	Y
TMFs	N	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N	Y
Hydropower improvement flows	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

- a Y = element included; N = element not included. Long-term strategies that include the element are shaded gray.
- b Activity ends after 2020.
- c Not to exceed one HFE (spring and fall) every other year.
- d Not to occur in first 2 years of LTEMP.
- e Not to occur in first 10 years of LTEMP.
- f Triggered in years with annual release volume ≥ 10 maf. Not implemented in the same water year as an extended-duration fall HFE.
- g Volume limited to that of a 96-hr, 45,000-cfs release.
- h Fall only, limited to four HFEs up to 250 hr if sediment will support, first implementation limited to 192 hr.
- i Spring and fall HFEs, no limit in number, up to 336 hr long if sediment will support.
- j Before and after spring and fall HFEs.
- k After fall HFEs only.
- l Before fall HFEs only.
- m Target 13°C.
- n Target 14°C, second 10 years only.

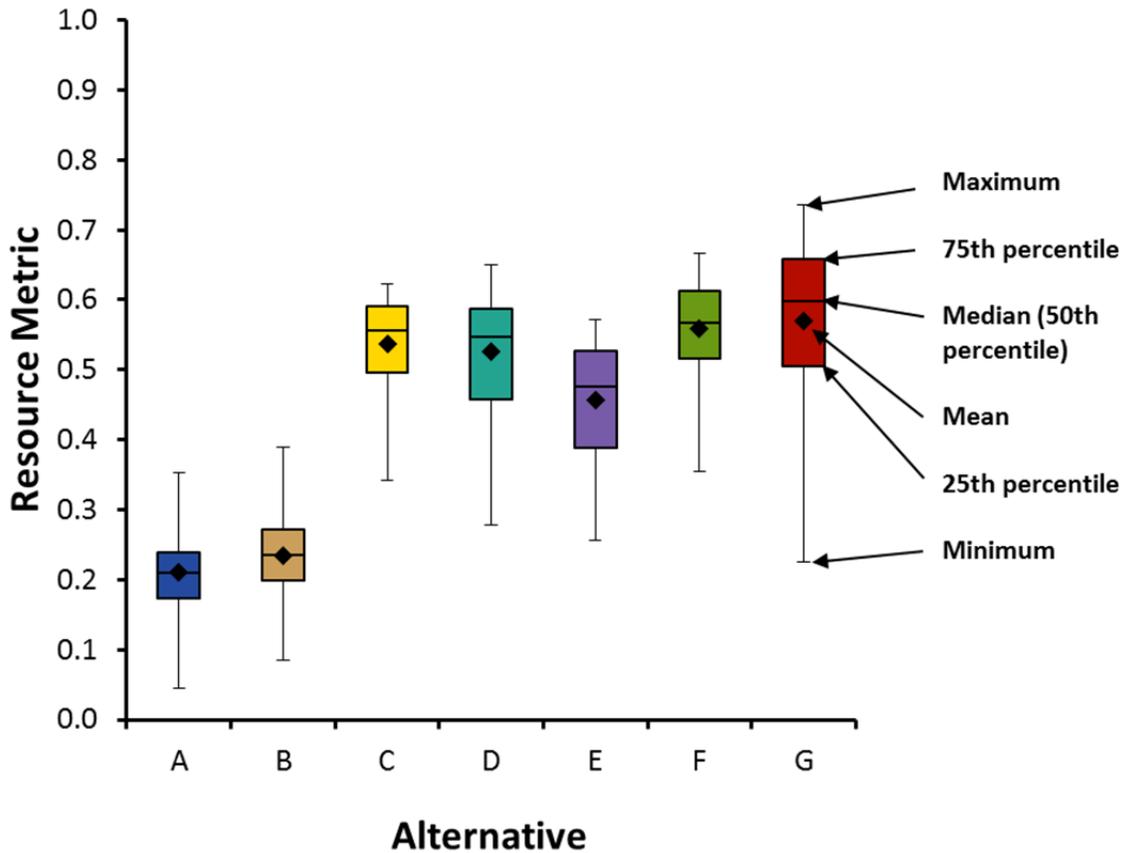
1 For those resource metrics that could be modeled quantitatively, a range of potential
2 hydrologic conditions and sediment conditions were modeled for a 20-year period that
3 represented the 20 years of the LTEMP. Twenty-one potential Lake Powell in-flow scenarios
4 (known as hydrology traces) for the 20-year LTEMP were sampled from the 105-year historic
5 record (water years 1906 to 2010) using the Index Sequential Method and selecting every fifth
6 sequence of 20 years. Using this approach, the first 20-year period considered was 1906–1925,
7 the second was 1911–1930, and so forth. As the start of traces reach the end of the historic
8 record, the years needed to complete a 20-year period are obtained by wrapping back to the
9 beginning of the historical record. For instance, the trace beginning in 1996 consists of the years
10 1996–2010 and 1906–1910, in that order. This method produced 21 hydrology traces for analysis
11 that represented a range of possible traces from dry to wet. Although these hydrology traces
12 represent the range of hydrologic conditions that occurred during the period of record, they may
13 not fully capture the driest years that could occur with climate change (see Section 4.17).
14

15 In addition to these 21 hydrology traces, three 20-year sequences of sediment inputs from
16 the Paria River sediment record (water years 1964 to 2013) were analyzed that represented low
17 (water years 1982 to 2001), medium (water year 1996 to 1965), and high (water years 2012 to
18 1981). In combination, the 21 hydrology traces and three sediment traces resulted in an analysis
19 that considered 63 possible hydrology-sediment conditions.
20

21 Models depicted in Figure 4-1 were used to generate resource metric values for each of
22 the alternatives under the 63 hydrology-sediment combinations. The values generated represent a
23 range of possible outcomes that in many cases were graphed using box-and-whisker plots
24 (Figure 4-2), which show the full distribution of values obtained as characterized by the
25 minimum, maximum, mean (average of all values), median (50% of the values are less than this
26 value), 25th percentile (25% of the values are less than this value), and 75th percentile (75% of
27 the values are less than this value).
28

29 Some resources or environmental attributes do not lend themselves to quantification
30 because there are insufficient data or understanding to support development of a model. In these
31 cases, the assessment presented in this chapter includes qualitative assessments of the likely
32 impacts on these resources and attributes. Qualitative analysis was particularly important for
33 effects related to personal and cultural values, as well as for an assessment of impacts on
34 resources not directly affected by river flow. In all cases, multiple lines of evidence were used to
35 assess impacts on resources.
36

37 The analytical results presented in this chapter represent in part the results of modeling
38 conducted in early 2015. After this modeling was completed, several adjustments were made to
39 specific operational and experimental characteristics of Alternative D (the preferred alternative)
40 based on discussions with Cooperating Agencies and stakeholders. These adjustments included
41 (1) a change in August volume in an 8.23-maf year from 750 to 800 kaf; (2) elimination of load-
42 following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of
43 load-following curtailment after a fall HFE; and (4) a ban on sediment-triggered spring HFEs in
44 the same water year as an extended-duration fall HFE. The description of Alternative D provided
45 in Section 2.2.4 represents the final version of the alternative that resulted from these changes.



1

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FIGURE 4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric Values

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For most resources, these changes are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D. Any expected noticeable differences are identified in the individual resource sections of this chapter.

8

9

10

Information sources used for this analysis included a large quantity of observational and research data collected since the start of dam operations and resulting from research programs originating under the Glen Canyon Adaptive Management Program (GCDAMP) established under the 1996 ROD and carried out by the Grand Canyon Monitoring and Research Center (GCMRC) and other researchers. The geographic region of interest and the topics and issues analyzed as determined from project scoping are described in Section 1.5.

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1 **4.2 WATER RESOURCES**
2

3 This section presents an analysis of
4 impacts on water resources of the Colorado River
5 between Glen Canyon Dam and Lake Mead, and
6 in Lake Powell and Lake Mead. This section is
7 organized into two broad topics—hydrology and
8 water quality. Hydrology encompasses those
9 topics related to the pattern and volume of
10 monthly, daily, and hourly releases from
11 Lake Powell that are a function of characteristics
12 of the LTEMP alternatives and how these release
13 patterns affect flows in the Colorado River and
14 the water surface elevations of Lake Powell and
15 Lake Mead. Water quality relates to non-flow
16 characteristics of the water, including
17 temperature, salinity, dissolved oxygen (DO),
18 turbidity, nutrients, metals, organics, and bacteria
19 and other pathogens. Analysis methods, a summary of impacts, and alternative-specific impacts
20 are presented in Sections 4.2.1, 4.2.2, and 4.2.3, respectively.
21

22 The water resources goal is to ensure water delivery to the communities and agriculture
23 that depend on Colorado River water consistent with applicable determinations of annual water
24 release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria
25 (LROC) for Colorado River Basin Reservoirs, which are currently implemented through the
26 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell
27 and Lake Mead.
28

29 Quantitative analysis of the effects of reservoir operations was performed using
30 Reclamation’s official basin-wide long-term planning model, Colorado River Simulation System
31 (CRSS). Model results provide a range of potential future system conditions such as reservoir
32 releases and storage, as well as operating tiers for Lake Powell and Lake Mead.
33

34 Direct impacts on water resources include those that may affect the annual operation of
35 Lake Powell and Lake Mead. While all the alternatives are consistent with the 2007 Interim
36 Guidelines (Reclamation 2007a), effects may include changes in the Lake Powell annual
37 operating tier, Lake Mead operating condition, and changes in annual release volume. The
38 primary aspect of reservoir operations that affects water resources is related to the monthly
39 distribution of the Lake Powell annual release volume and its resulting impact on reservoir
40 elevations, operating tiers, and annual release volumes. The impact analysis for water resources
41 reflects the 20-year LTEMP period, which, for modeling purposes, was from October 1, 2013, to
42 September 30, 2033.
43
44

Issue: How do the alternatives affect water resources in the project area?

Impact Indicators:

- Lake Powell releases (annual, monthly, daily, and hourly)
- Lake Powell and Lake Mead reservoir elevations
- Lake Powell annual Operating Tier and Lake Mead operating conditions
- Monthly, hourly, and daily patterns in Colorado River flows downstream of Glen Canyon Dam

1 **4.2.1 Analysis Methods**

2
3
4 **4.2.1.1 Hydrology**

5
6
7 **Annual and Monthly Operations**

8
9 Modeling of the Colorado River system was conducted to determine the potential effects
10 of LTEMP alternatives on annual and monthly operations that could affect Colorado River
11 system conditions (e.g., reservoir elevations, reservoir releases, and river flows) as compared to
12 Alternative A (the No Action Alternative). Due to uncertainties associated with future inflows
13 into the system, multiple simulations were performed for each alternative in order to quantify the
14 uncertainties in future conditions, and the modeling results are expressed in probabilistic terms.
15

16 Future Colorado River system conditions under the LTEMP alternatives were simulated
17 using CRSS. The model framework used for this process is the commercial software
18 RiverWare™ (Zagona et al. 2001), a generalized river basin modeling software package
19 developed by the University of Colorado through a cooperative arrangement with Reclamation,
20 the Tennessee Valley Authority, and the U.S. Army Corps of Engineers. CRSS was originally
21 developed by Reclamation in the early 1970s, was converted to RiverWare™ in 1996, and has
22 been used as Reclamation’s primary Colorado River Basin-wide planning model since that time.
23 Previous studies that used CRSS include the 1996 Glen Canyon Operations EIS
24 (Reclamation 1995), the 2007 Interim Guidelines Environmental Impact Statement (EIS)
25 (Reclamation 2007a), and the Colorado River Basin Water Supply and Demand Study, referred
26 to as the Basin Study (Reclamation 2012a).
27

28 CRSS simulates the operation of 12 major reservoirs on the Colorado River and provides
29 information regarding the projected future state of the system on a monthly basis; the model
30 simulates the amount of water in storage, reservoir elevations, releases from the dams, the
31 amount of water flowing at various points throughout the system, and diversions to and return
32 flows from water users throughout the system. The basis of the simulation is a mass balance
33 (or water budget) calculation that accounts for water entering the system, water leaving the
34 system (e.g., from consumptive use of water, trans-basin diversions, and evaporation), and water
35 moving through the system (e.g., either stored in reservoirs or flowing in river reaches). Further
36 explanation of the model is provided in Appendix D. CRSS was used to project the future
37 conditions of the Colorado River system for the 20-year LTEMP period, which for modeling
38 purposes, was water years 2013 through 2033.¹
39

40 The input data for the model includes monthly natural inflows; various physical process
41 parameters such as the evaporation rates for each reservoir; initial reservoir conditions on
42 January 1, 2013; and the future projected diversion and depletion schedules for entities in the
43 seven Basin States (Appendix D) and for Mexico. These future schedules are based on demand
44 and depletion projections prepared and submitted by the Basin States for the Basin Study, and

¹ The water year is defined as October 1 through September 30 of the following calendar year.

1 assume the Current Projected demand scenario (Schedule A) from the Basin Study. For purposes
2 of this DEIS, depletions (or water consumptive uses) are defined as diversions from the river less
3 return flow credits, where applicable.
4

5 For each alternative, the rules of operation of the Colorado River mainstem reservoirs,
6 including Lake Powell and Lake Mead, were developed as input to the model. These sets of
7 operating rules describe how water would be released and delivered under various hydrologic
8 conditions. In the modeling of all alternatives, the operations of Lake Powell and Lake Mead are
9 assumed to revert back in 2027 to the assumptions used to represent the No Action Alternative in
10 the 2007 Interim Guidelines. Because CRSS is a monthly model, reservoir operations at sub-
11 monthly intervals (e.g., daily release fluctuations, ramp rates, HFEs, and TMFs) were not
12 explicitly modeled in CRSS, but they were modeled using other modeling software. Further
13 explanation of the operating rules for each alternative is provided in Section 2.2.
14

15 Long-term planning models, such as CRSS, are typically used to project future river and
16 reservoir conditions over a period of years or decades into the future. There are numerous inputs
17 to, and assumptions made by, these models. As the period of analysis increases (for this DEIS
18 the analysis period is 20 years), the uncertainty in those inputs and assumptions also increases.
19 Consequently, these models are not used to predict future river and reservoir conditions, but
20 rather to project the range of possible effects. When analyzing the potential hydrologic impacts
21 from operational alternatives, most inputs, as well as other key modeling assumptions, are held
22 constant for each alternative to isolate the differences due to each alternative. In this manner, the
23 analyses for each alternative may be compared, and thus a relative comparison of the impacts of
24 alternatives can be made.
25

26 Uncertainties in CRSS output are due to assumptions in input, including parameterization
27 of physical processes such as reservoir evaporation and bank storage, the future diversion and
28 depletion schedules for the entities throughout the Colorado River Basin, and the future inflows
29 into the system. In addition, much of the input data are derived from actual measurements that
30 have uncertainties associated with them. For example, natural flows (i.e., those flows that would
31 occur in the absence of dams, reservoirs, diversions, and withdrawals) are partially based on data
32 acquired from streamflow gages, which, when calibrated properly, have uncertainties of about
33 5 to 10%. Although these data are generally the best available, all of these uncertainties limit the
34 absolute accuracy of the model. However, by holding most inputs constant, the relative
35 comparisons among modeled conditions are still valid.
36

37 Despite the differences in some of the modeling assumptions under the LTEMP
38 alternatives, the future conditions of the Colorado River system (e.g., future Lake Mead and
39 Lake Powell elevations) are most sensitive to future inflows. Observations over the period of
40 historical record (1906 through 2010) show that inflow into the system has been highly variable
41 from year to year and over decades. Because it is impossible to predict the actual future inflows
42 for the next 20 years, a range of possible future inflows are analyzed and used to quantify the
43 probability of occurrences of particular events (e.g., higher or lower reservoir elevations). This
44 technique, performed for the hydrologic analysis presented here, involves multiple simulations
45 for each alternative, one for each future hydrologic sequence.

1 The future hydrology used as input to the model consisted of samples taken from the
2 historical record of natural flow in the river system over the 105-year period from 1906 through
3 2010 from 29 individual inflow points (or nodes) on the system. The locations of the inflow
4 nodes are described in Appendix D.

5
6 Typically, CRSS is run with the full suite of available natural flow traces created using a
7 resampling technique known as the Indexed Sequential Method (ISM) (Ouarda et al. 1997).
8 Using the ISM on a 105-year record (1906–2010) results in 105 inflow traces (i.e., plausible
9 inflow sequences). For this DEIS, every fifth trace from the 105 natural flow traces was selected,
10 resulting in 21 traces that are considered representative of the full period of record (Appendix D).
11 For the climate change analysis described in Section 4.26, CRSS was run with 112 natural flow
12 traces developed from downscaled general circulation model projected hydrologic traces
13 (Reclamation 2011f).

14
15 As shown in Figure 4-1, a full set of resource models was used to analyze resource
16 impacts, and CRSS output served as input for most of these models. Reservoir operations under
17 each alternative were explicitly modeled in CRSS. Each alternative was modeled in CRSS with
18 21 different potential hydrology scenarios to account for uncertainty in future hydrologic
19 conditions. Comparisons between alternatives are made on these 21 simulations per alternative.
20 The interquartile range indicates that 50% of the estimated values fall within this range, 25% of
21 the values are below this range, and 25% are above this range.

22 23 24 **Daily and Hourly Operations**

25
26 Monthly volumes under each alternative, as predicted by CRSS and described in the
27 previous section, were used as input to determine daily and hourly patterns of releases using
28 GTMax-Lite, a program developed by Argonne National Laboratory. Within each month, this
29 program determines the pattern of daily and hourly releases that would maximize hydropower
30 value based on CRSS-predicted monthly volume, reservoir elevation, hourly electricity market
31 prices, and the operational constraints of each alternative, including maximum and minimum
32 flows, ramping rates, and allowable daily range.

33
34 Hourly flows were generated using the GTmax-Lite model for the 20-year LTEMP
35 period under each of the 21 hydrology scenarios and three sediment scenarios that were analyzed
36 for each alternative. This resulted in 63 unique 20-year simulations for each alternative. Daily
37 and hourly flow data were statistically analyzed to generate values of mean daily flow, mean
38 daily change (maximum flow minus the minimum flow for each day), and monthly volume for
39 each alternative, and to show the variation in these variables over the range of scenarios
40 analyzed.

1 **4.2.1.2 Water Quality**
2

3 This section describes the methods used to determine the potential effects on water
4 quality associated with the LTEMP alternatives. Details of the methodologies used are presented
5 in Appendix F of this DEIS.
6

7 Using the hydrologic output from the CRSS RiverWare™ model (see Section 4.2.1.1),
8 the CE-QUAL-W2 model (Cole and Wells 2003) was used to simulate water temperatures of
9 Lake Powell (including dam releases).
10

11 Temperature exerts a major influence on biological and chemical processes. Aquatic
12 organisms have preferred temperature ranges that influence their abundance and distribution.
13 DO concentrations are generally lower, while salinity levels, nutrient, and pathogen
14 concentrations are higher in warmer water. Temperature modeling for the Colorado River below
15 Glen Canyon Dam was performed using the method described in Wright, Anderson et al. (2008).
16 This model computes gains and losses of heat as water moves down the river. In general,
17 predicted downstream temperatures are driven by the release temperature from Glen Canyon
18 Dam, equilibrium water temperature (i.e., the temperature the water would eventually reach if it
19 did not flow; dependent on air temperature, direct insolation, wind patterns, and evaporation),
20 temperature and volumes of tributary inflows, and a heat exchange coefficient, which are all
21 complex functions of environmental conditions (Walters et al. 2000).
22

23 The salinity module of the CRSS RiverWare™ model was used to analyze changes in
24 salinity concentration for Colorado River reaches from Lake Powell to Imperial Dam, which is
25 located downstream of Hoover Dam and Lake Mead. Monthly salinity estimates were aggregated
26 to annual values because the salinity criteria/standards set for Colorado are based on flow-
27 weighted average annual salinity (mg/L). Other water quality parameters (e.g., DO, turbidity,
28 nutrients, metals, organics, and bacteria/pathogens) were not modeled quantitatively. Qualitative
29 assessments of these parameters in the Colorado River between Lake Powell and Lake Mead
30 were based on previous scientific studies and historical data, including published research,
31 related EISs, and Environmental Assessments (EAs).
32

33 Detailed modeling for Lake Mead was conducted by the Southern Nevada Water
34 Authority because of concerns related to the potential effects of LTEMP alternatives on the
35 quality of municipal water supplies. The temperature modeling was performed using the model
36 described in Flow Science (2011). The Lake Mead Model (LMM) uses the ELCOM (Estuary,
37 Lake and Coastal Ocean Model) code to simulate hydrology and conservative constituents, and
38 CAEDYM (Computational Aquatic Ecosystem Dynamics Model) code for simulating
39 biogeochemical processes.
40

41 Ten 2-year model scenarios were chosen to represent a subset of LTEMP alternatives that
42 could result in important water quality impacts (Tietjen 2015). The goal of modeling was to
43 indicate the possibility of effects that could occur. The 10 selected scenarios were separated into
44 three general elevation-based scenarios. The first scenario covers water years 2014–2015, which
45 have higher relative lake surface elevations (1,080–1,110 ft AMSL), and models hydrology
46 trace 8, sediment trace 1, and Alternatives A, E (represented by two long-term strategies,

1 1 and 5), and F. The second scenario looks at water years 2018–2019, with lower relative lake
2 surface elevations (1,040–1,060 ft AMSL), and models hydrology trace 11, sediment trace 1, and
3 Alternatives A, E (long-term strategy 1), and F. The third scenario covers water years 2019–
4 2020, which displays a high starting lake surface elevation that decreases significantly
5 (1,125–1,070 ft AMSL), and hydrology trace 18, sediment trace 1, and models Alternatives A, E
6 (long-term strategy 6), and F.

9 **4.2.2 Summary of Impacts**

10
11 The overall impacts of the seven LTEMP alternatives on the hydrology and water quality
12 of Lake Powell, the Colorado River below Glen Canyon Dam, and Lake Mead are presented in
13 this section and summarized in Table 4.2-1. A discussion of alternative-specific impacts is
14 provided in Section 4.2.3.

17 **4.2.2.1 Hydrology**

18
19 Impacts on annual, monthly, daily, and hourly reservoir releases, elevations, and annual
20 operating tiers, as well as water delivery performance metrics, are discussed in the subsections
21 below.

24 **Lake Powell Operating Tier and Annual Release Volume**

25
26 The Lake Powell annual operating tier and annual release volume are primarily driven by
27 hydrological conditions in a given year. The modeled Lake Powell annual release volumes range
28 from 7.0 maf to 19.2 maf, with a median value of 8.23 maf, across all years, traces, and
29 alternatives.

30
31 The Lake Powell annual release volume is driven by the annual operating tier, which is
32 set based on projections of, as appropriate, end-of-calendar year and end-of-water year,
33 elevations in Lake Powell and Lake Mead. Under the 2007 Interim Guidelines, Lake Powell
34 operates under four operating tiers. Each operating tier has a specific logic for determining the
35 required annual release within that tier. Depending on the operating tier, the annual release is
36 either a set volume determined at the beginning of the water year, or a variable volume based on
37 projected and actual inflows and resulting Lake Powell and Lake Mead elevations and storages.

38
39 The selection of the annual operating tier at Lake Powell and Lake Mead and the annual
40 release volumes can, in some instances, be affected by the differing monthly release patterns of
41 the LTEMP alternatives. While all of the alternatives, including Alternative A (no action
42 alternative), were designed to be implemented to comply with the 2007 Interim Guidelines
43 (Reclamation 2007a) during their effective period, nevertheless there can still be differences
44 regarding operating tier selections and annual volumes among alternatives that are small and
45 minimal in the long term (i.e., the multi-decade analysis performed in this DEIS). It is important
46 to emphasize that all alternatives implement the rules of the 2007 Interim Guidelines through

1 **TABLE 4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water Quality**

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology							
Overall summary of impacts	No change from current condition	Compared to Alternative A, no change from current condition related to lake elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months. Hydropower improvement flows would cause even greater mean daily flow changes.	Compared to Alternative A, some change from current condition related to lake elevations, annual operating tiers, monthly release volumes, and mean daily flows; lower mean daily changes in flow in all months.	Compared to Alternative A, negligible change from current condition related to lake elevations; no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months.	Compared to Alternative A, negligible change from current condition related to lake elevations; no change in annual operating tiers; more even monthly release volumes and mean daily flows; higher mean daily changes in flow in all but Sept. and Oct.	Compared to Alternative A, some change from current condition related to lake elevations and annual operating tiers; large changes in monthly release volumes and mean daily flows; steady flows throughout the year.	Compared to Alternative A, negligible change from current condition related to lake elevations and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year.
Lake Powell and Lake Mead Reservoir elevations	No change from current condition; reservoir elevations vary significantly with inflow hydrology; Lake Powell and Lake Mead operate at times within the full range of operating elevations.	Same as Alternative A for end-of-December elevations for Lake Powell and Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 1.5 ft higher at Lake Powell and 0.6 ft lower at Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 0.2 ft higher at Lake Powell but the same at Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 0.3 ft higher at Lake Powell and 0.1 ft lower at Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 3.2 ft higher at Lake Powell and 2.9 ft lower at Lake Mead, the largest difference of all alternatives.	Compared to Alternative A, end-of-December elevations would be on average 0.4 ft lower at Lake Powell and 1.4 ft higher at Lake Mead.

4-13

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Hydrology (Cont.)</i>							
Lake Powell annual operating tier	No change from current condition; Alternative A would operate at times within each of the four operating tiers during the period 2013–2026 and at times within both operating tiers during the period 2027–2033.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Compared to Alternative A, would operate in a different tier an average of 0.7% of years; there would be the same frequency of operating tiers, but different timing during the analysis period.

4-14

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Hydrology (Cont.)</i>							
Monthly release volume	No change from current condition; monthly volumes would be highest in Dec., Jan., Jun., Jul., Aug., and Sept. (670,000 ac-ft to 1,500,000 ac-ft; 570,000 to 1,200,000 ac-ft in other months).	Same as Alternative A.	Compared to Alternative A, higher volumes in Feb. through May (by 82,000 to 157,000 ac-ft); lower in Aug., Sept., and Oct. (by 111,000 to 200,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 43,000 to 98,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 60,000 to 127,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 45,000 to 128,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 30,000 to 242,000 ac-ft).	Compared to Alternative A, much higher volume in Apr., May, and Jun. (by 439,000 to 651,000 ac-ft); much lower in Dec., Jan., Jul., Aug., and Sept. (by 214,000 to 433,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Mar., and Apr. (by 71,000 to 286,000 ac-ft); lower in Dec., Jan., Jul., and Aug. (by 139,000 to 196,000 ac-ft).
Mean daily flow	No change from current condition; mean daily flows are highest in Dec., Jan., Jun., Jul., Aug., and Sept. (11,200 to 24,600 cfs; 9,400 to 14,400 cfs in other months).	Same as Alternative A.	Compared to Alternative A, higher mean daily flow in Feb. through May (by 1,300 to 2,500 cfs); lower in Aug., Sept., and Oct. (by 1,800 to 3,300 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 3,000 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 1,000 to 2,100 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 2,100 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 500 to 4,000 cfs).	Compared to Alternative A, much higher mean daily flow in Apr. through Jun. (by 7,400 to 10,600 cfs); much lower in Dec. and Jan. and Jul. through Sept. (by 3,600 to 7,000 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Mar., Apr. (by 1,200 cfs to 4,800 cfs); lower in Dec., Jan., Jul., and Aug. (by 2,300 to 3,200 cfs).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Mean daily change in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs in Dec., Jan., Jun., Jul., Aug., and Sept.; 2,600 to 6,400 cfs in other months.	Compared to Alternative A, mean daily change higher in all months (range about 2,500 to 12,000 cfs).	Compared to Alternative A, mean daily change lower in all months (about 1,300 cfs to 6,200 cfs).	Compared to Alternative A, mean daily change slightly higher in Oct. through Jun., same or less in Jul. through Aug. (range about 2,700 to 7,600 cfs).	Compared to Alternative A, mean daily change higher in all months but Sep. and Oct. (range about 1,100 to 9,600 cfs).	Mean daily change is zero except for ramping up and down from spring and fall HFEs.	Mean daily change is zero except for ramping up and down from spring and fall HFEs.
Water Quality							
Overall summary of impacts	No change in temperature or other water quality indicators from current conditions.	Negligible differences in temperature or other water quality indicators.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A and the other alternatives, greatest summer warming and potential for bacteria and pathogens.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.
Water temperature (change from Lees Ferry to Diamond Creek)	No change from current conditions; summer warming would be lowest among alternatives (average 5.6°C).	Same as Alternative A.	Summer warming would be higher than under Alternative A (average 5.8°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be highest among alternatives (average 6.8°C).	Summer warming would be higher than under Alternative A (average 6.2°C).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Water Quality (Cont.)							
Salinity	Negligible change from current condition. Negligible alternative-specific differences (<2.5%) expected because, regardless of operating conditions, salinity would not increase over time or exceed control criteria.						
Turbidity	Negligible change from current condition. No alternative-specific differences expected because potential turbidity increases due to scouring during HFEs are expected to be temporary and any observed fluctuations recover quickly when lower flows return. Effects of operational changes related to tributaries are currently unknown.						
Bacteria and pathogens	No change from current condition.	Slightly lower probability of the occurrence of bacteria and pathogens compared to Alternative A because of higher within-day fluctuations.	Occasional low summer flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Occasional low summer flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Occasional low summer flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Annual low steady flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Year-round steady flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.
Nutrients	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, waters are expected to remain relatively low in nutrients.						
Dissolved oxygen	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, DO concentrations are expected to remain within the accepted healthy range for fish.						
Metals/ radionuclides	Negligible change from current condition. No alternative-specific differences expected because operational changes will not affect metal/radionuclide concentrations. There are no concerns related to these substances because levels do not exceed any enforceable human-health-based standards or guidance values.						
Organic/other contaminants	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, organic and other contaminant concentrations are expected to remain below those considered toxic.						

1 2026 regarding annual release volumes from Glen Canyon Dam. Three causes contribute to the
2 identified model results showing differences in operating tier or different annual release
3 volumes:

- 4
- 5 • October to December release ratio,
- 6
- 7 • Differences in evaporation and bank storage,² and
- 8
- 9 • Differences in equalization releases when maximum release is a constraining
10 factor.
- 11

12 These topics are described next.

13

14

15 **October to December Release Ratio.** Alternatives that release proportionally less
16 volume during October through December, relative to the rest of the water year, result in a
17 slightly lower end-of-year Lake Powell elevation (and slightly higher end-of-year Lake Mead
18 elevation), and can, accordingly in those circumstances, when Lake Powell elevation is projected
19 to be close to an operating tier threshold, result in a different operating tier selection, potentially
20 impacting the implementation of a different operating tier at Lake Powell and Lake Mead, as
21 well as different annual volumes. This effect (a changed operating tier) is projected to occur very
22 infrequently (0 to 2.1 % of years, depending on the alternative) and constituted all occurrences of
23 operating tier differences from Alternative A in this modeling. Alternatives with the same
24 October through December volume as Alternative A (2,000 kaf in an 8.23-maf year) did not
25 result in a different operating tier. Alternatives B, D, and E also have October–December
26 volumes of 2,000 kaf, but Alternatives C, F, and G have October–December volumes of
27 1,790 kaf, 1,466 kaf, and 2,075 kaf, respectively.

28

29

30 **Effects Due to Differences in Evaporation and Bank Storage.** Changes in the monthly
31 pattern of releases result in differences in evaporation and losses or gains caused by bank
32 storage, which in turn can affect the end-of-year pool elevation, and in some cases could affect
33 the operating tier or annual release volume in equalization or balancing years. Alternatives that
34 release proportionally less volume early in the water year typically result in a higher Lake Powell
35 elevation and larger surface area in the summer. This can result in slightly higher losses from
36 evaporation and bank storage during such periods. In certain operating tiers (those with a set
37 volume release or those dependent on Lake Mead’s elevation), this can result in a slightly
38 different end-of-year elevation at Lake Powell. If Lake Powell is close to an operating tier
39 threshold the following water year, a different operating tier could be triggered in the following
40 water year due to differences in evaporation and bank storage. This effect did not show up in this
41 modeling, but in theory it could occur.

42

43

² Water absorbed and stored in the banks of a reservoir and returned in whole or in part as the level of the reservoir surface falls.

1 **Effects Due to Differences in Equalization Releases when Maximum Release Is a**
2 **Constraining Factor.** Equalization release volumes can be affected by the annual pattern of
3 monthly volumes. Alternatives that have higher releases earlier in the water year are able to
4 release more water in years when the maximum release through the powerplant becomes a
5 limiting factor to equalizing within the water year. As hydrologic conditions change throughout
6 the water year, the annual release volume also shifts. In years when the annual release volume
7 increases throughout the year, it may not be possible to release it all in the remaining months of
8 the water year through the powerplant turbines; thus, some must be released the following water
9 year. Generally, the action alternatives pass more water earlier in the water year (through July)
10 and thus have less potential for annual releases extending beyond the water year than
11 Alternative A (0 to 200 kaf less, depending on the alternative). This can result in different annual
12 volumes, but that difference is made up in the following water year. This effect does not result in
13 different operating tiers.

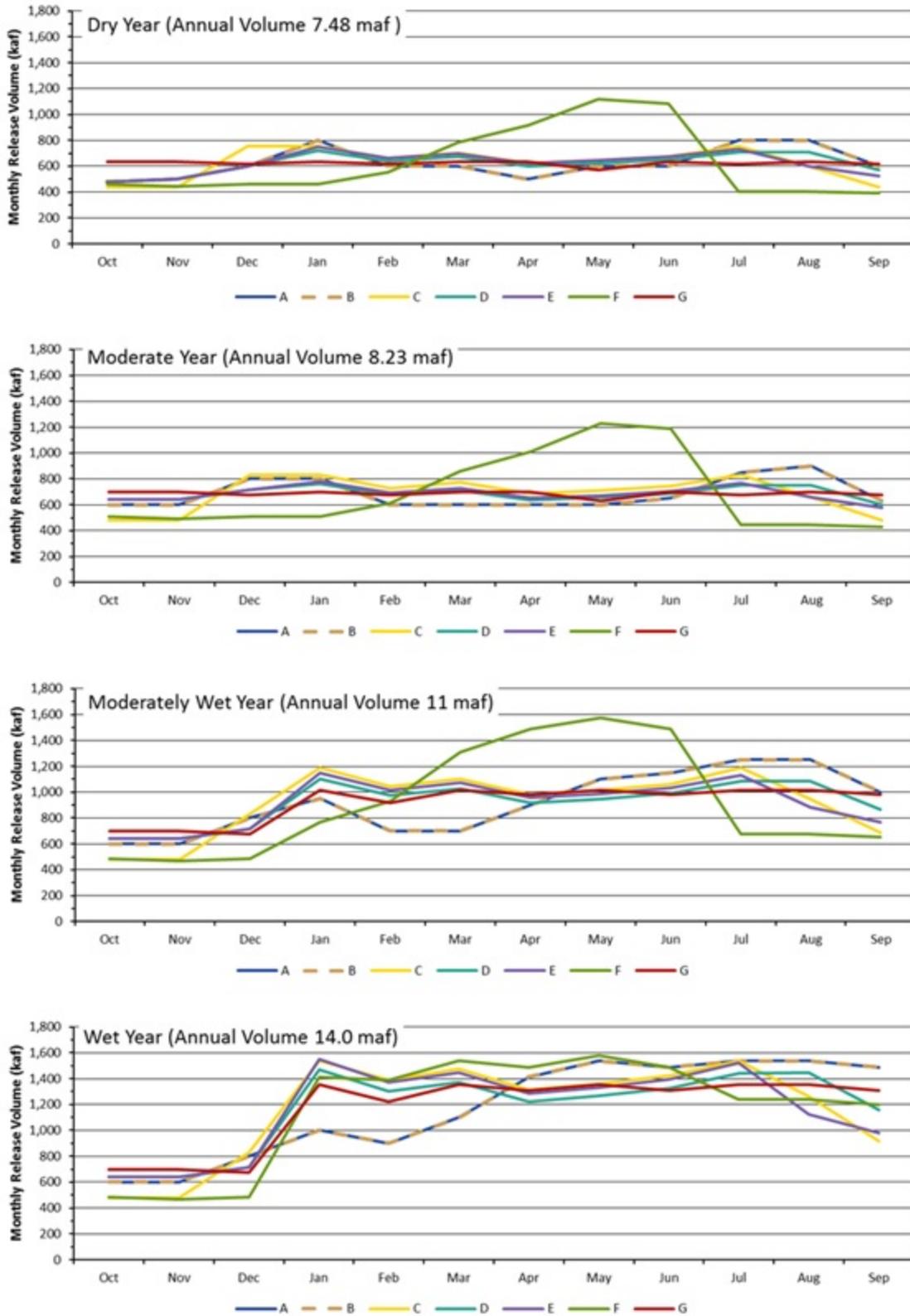
14 15 16 **Monthly Releases** 17

18 Although annual release volumes would be nearly the same under each of the LTEMP
19 alternatives, the monthly patterning of that annual volume varies significantly among the
20 alternatives. Monthly release patterns for each of the alternatives in years with different annual
21 release volumes are shown in Figure 4.2-1. Monthly releases were shaped for each alternative in
22 an 8.23-maf year and then generally scaled proportionally to the 8.23-maf pattern relative to the
23 annual volume.³ For example, 763 kaf in January for Alternative D in an 8.23-maf year scaled to
24 1,104 kaf in January for an 11-maf year. For years when the annual volume was large enough
25 that monthly releases were limited by the maximum release capacity of Glen Canyon Dam, the
26 monthly distribution of releases became more similar across alternatives (Figure 4.2-1). Monthly
27 release volumes for different annual releases are included in Appendix D.

28
29 Monthly releases sometimes would be limited by the minimum or maximum release
30 constraints at Glen Canyon Dam. In low annual volume release years, monthly volumes
31 sometimes would be increased to ensure that the minimum hourly release objective of each
32 alternative could be maintained throughout the month. In high annual release years, monthly
33 volumes sometimes would be decreased because they were capped at the maximum release
34 capacity (45,000 cfs), and the remaining volume was released in the following month(s).
35 See Appendix D for further detail.

36
37 Operationally, annual releases and the associated monthly releases are affected by
38 hydrologic uncertainty. In some operating tiers, Lake Powell's annual release is determined by
39 end-of-water year target elevations or storages of Lake Powell and Lake Mead. Because the
40 actual inflow volume is not known until the end of the water year, reservoir operators utilize
41 inflow forecasts throughout the year to project the expected annual release volume and allocate
42 the monthly releases accordingly. As hydrologic conditions change throughout the water year,

³ Note that adjustments to Alternative D made after modeling was completed resulted in a 50-kaf increase in August (changed from 750 to 800 kaf) and a corresponding 25-kaf decrease in May and June (changed from 657 to 632 kaf and 688 to 663 kaf, respectively) in an 8.23-maf year.



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FIGURE 4.2-1 Monthly Releases under Each Alternative in Years with Different Annual Release Volumes

1 the annual release volume also shifts. This effect of hydrologic uncertainty is captured in CRSS
2 through a forecasting algorithm. Resulting monthly releases, therefore, may not scale exactly
3 proportionally with the final total annual release volume.
4

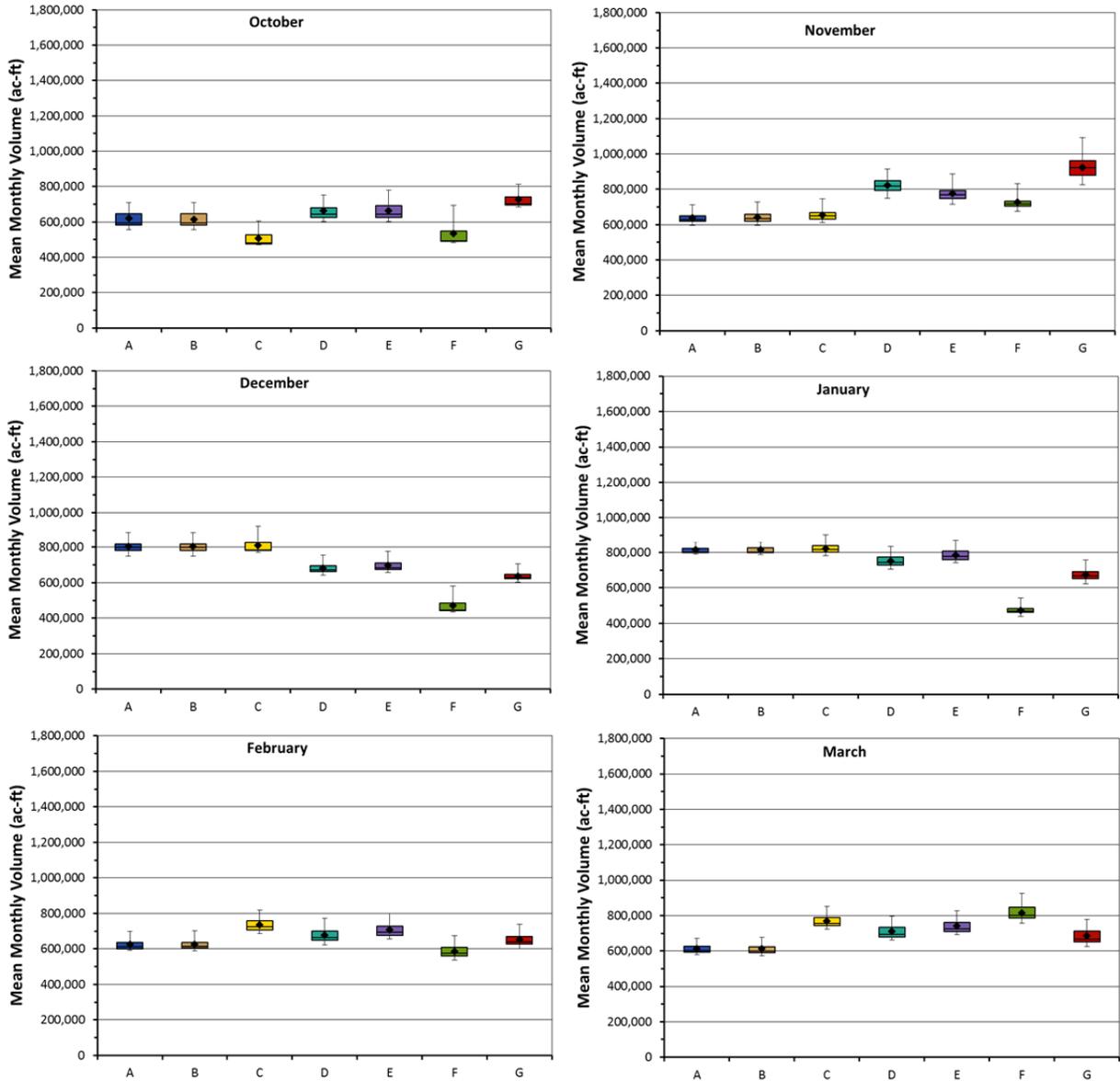
5 Monthly release volume can also be affected by HFEs. For HFEs that require more water
6 than was already allocated for the given month of the HFE, water is reallocated from later
7 months to ensure the water year release volume remains the same. The monthly reallocation of
8 releases to support a HFE does not affect the Lake Powell operating tier. See Appendix D for
9 further detail.
10

11 Monthly releases can also be affected by low summer flows. Low summer flows would
12 be implemented as an experimental component under Alternatives C, D, and E. During years
13 with low summer flows, releases would be lower than typical in July, August, and September
14 and proportionally higher in May and June, in order to maintain the same annual release volume.
15 Subject to the decision-making process outlined in Section 2.2.4.2, low summer flows may be
16 implemented if three conditions are met: (1) the projected annual release was less than 10 maf;
17 (2) the projected temperature at the confluence with the Little Colorado River in July, August, or
18 September was < 13°C (Alternatives C and E) or 14°C (Alternative D); and (3) switching to the
19 low summer flow pattern resulted in temperatures of 13°C (Alternatives C and E) or 14°C
20 (Alternative D) in those months. For those alternatives with low summer flows, the number of
21 those flows in the 20-year period was estimated to range from zero to four occurrences.
22 Depending on the alternative, the average ranges from 0.7 to 1.8 low summer flows per 20-year
23 run. See Appendix D for further detail.
24

25 Mean monthly release volumes averaged over all years within each run are shown in
26 Figure 4.2-2. The variability in these values reflects the effect on operations of natural variability
27 in inflows observed in the historical record. The differences among alternatives in mean monthly
28 release volumes are a function of the monthly volume patterns established in the definition of
29 each alternative (see Chapter 2 for a description of these operational constraints).
30

31 Within alternatives, mean monthly volumes would vary the most among the scenarios in
32 the months of June through September (Figure 4.2-2). This pattern of variability is a result of
33 adjustments in operations in the latter half of the water year in response to forecasts that become
34 more certain after June 1. During the first half of the water year, operations tend to be more
35 conservative (less variable) to ensure sufficient water remains for the remainder of the year to
36 meet minimum flows.
37

38 Mean monthly volumes under Alternative F are consistently the most different from other
39 alternatives, with volume being lower in December, January, July, August, and September, but
40 higher in April, May, and June (Figure 4.2-2). This monthly pattern is intended to more closely
41 match a natural hydrograph with high spring flows and low summer through winter flows. Other
42 variations among alternatives are less apparent, although Alternatives C and E both target lower
43 August and September volumes to conserve sediment prior to fall HFEs.
44
45

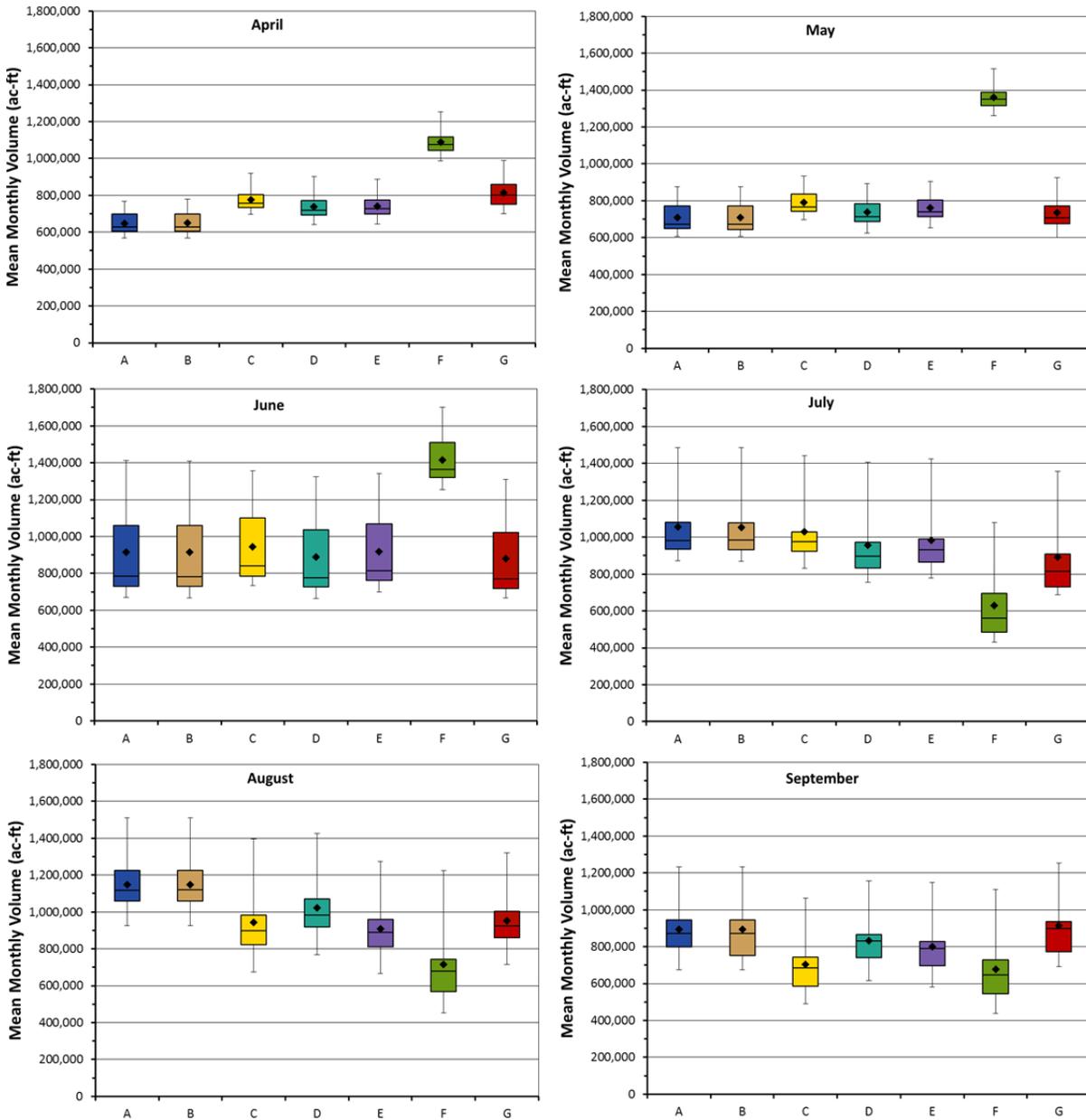


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2 **FIGURE 4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean,**
 3 **Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology**
 4 **Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years**
 5 **within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median;**
 6 **lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker =**
 7 **minimum; upper whisker = maximum.)**

8

9



1
 2 **FIGURE 4.2-2 (Cont.)**

3
 4
 5 **Daily and Hourly Releases and Ramp Rates**

6
 7 For most alternatives, releases from Glen Canyon Dam fluctuate throughout the day in
 8 response to hydropower demand. Releases are generally higher during the day when there is a
 9 higher demand for hydropower, and lower during the night when the demand is lower. The
 10 fluctuation within a day (i.e., from nighttime low to daytime high) varies by alternative and is
 11 typically relative to the monthly release volume. For example, months with a higher release
 12 volume typically have a larger daily range of releases. Two alternatives, Alternatives F and G, do
 13 not have daily and hourly release fluctuations.

1 The range of daily releases is further defined by a required minimum release and is
2 alternative specific. The scheduled hourly release rate must be equal to or greater than the
3 prescribed minimum release. The minimum release during the daytime is typically higher than
4 the minimum release during the nighttime.
5

6 The peak release in a day is determined by the maximum allowable daily fluctuation, and
7 the daily and monthly release volume. In cases when the required monthly release is very large,
8 the peak daily release could be limited by reservoir outlet works capacity, which is a function of
9 reservoir head. Generally speaking, the maximum possible release without using the spillway
10 was computed as 45,000 cfs. The actual maximum release may be lower, depending on reservoir
11 elevation and the number of available hydropower units.
12

13 Ramp rates, the change in release from one hour to the next, are also specific to each
14 alternative (Chapter 2). Ramp rates down vary by alternative; ramp rates up are the same for all
15 alternatives (Chapter 2, Table 2-1). For all alternatives, the ramp rate up is faster than the ramp
16 rate down.
17

18 Daily release volumes vary throughout the week relative to hydropower demand. Release
19 volumes are typically larger during weekdays when the demand for hydropower is higher and
20 release volumes are lower during the weekends and holidays.
21

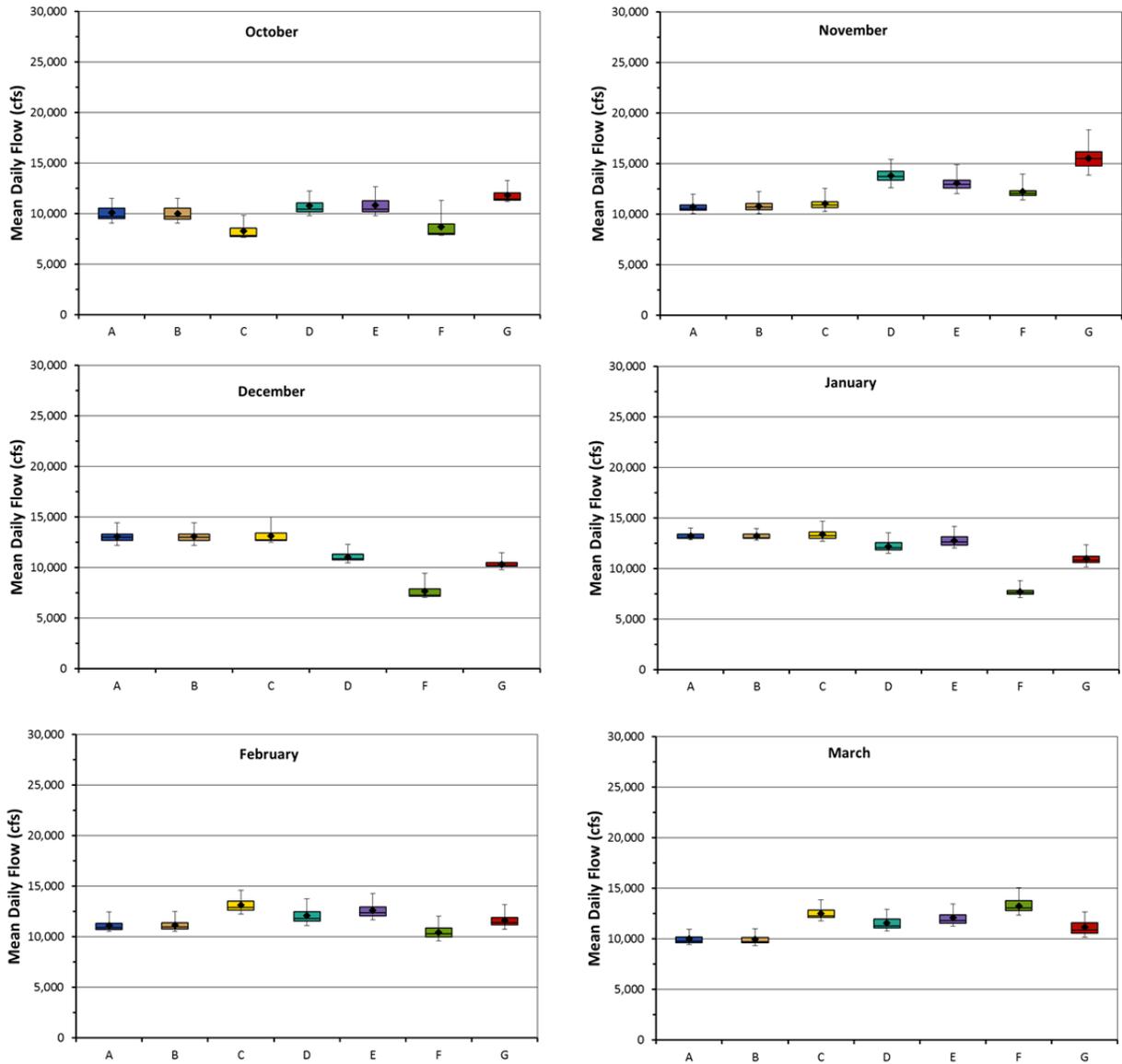
22 Mean daily flow and mean daily change vary among alternatives, in part due to
23 differences in the monthly volume patterns established for each alternative, but also as a result of
24 operational constraints characteristic of each alternative (see Chapter 2 for a description of these
25 operational constraints) (Figures 4.2-3 and 4.2-4).
26

27 Within alternatives, mean daily flows would vary the most among the scenarios in the
28 months of June through September (Figure 4.2-3). This pattern can be attributed to increased
29 variability in monthly volume, as described in the previous section.
30

31 Mean daily flows under Alternative F are consistently the most different from other
32 alternatives, with mean daily flows being lower in December, January, July, August, and
33 September, but higher in April, May, and June (Figure 4.2-3). These differences are a result of
34 the monthly release pattern of this alternative, as described in the previous section. Other
35 variations among alternatives are less apparent, although Alternatives C and E both target lower
36 August and September volumes to conserve sediment prior to fall HFEs.
37

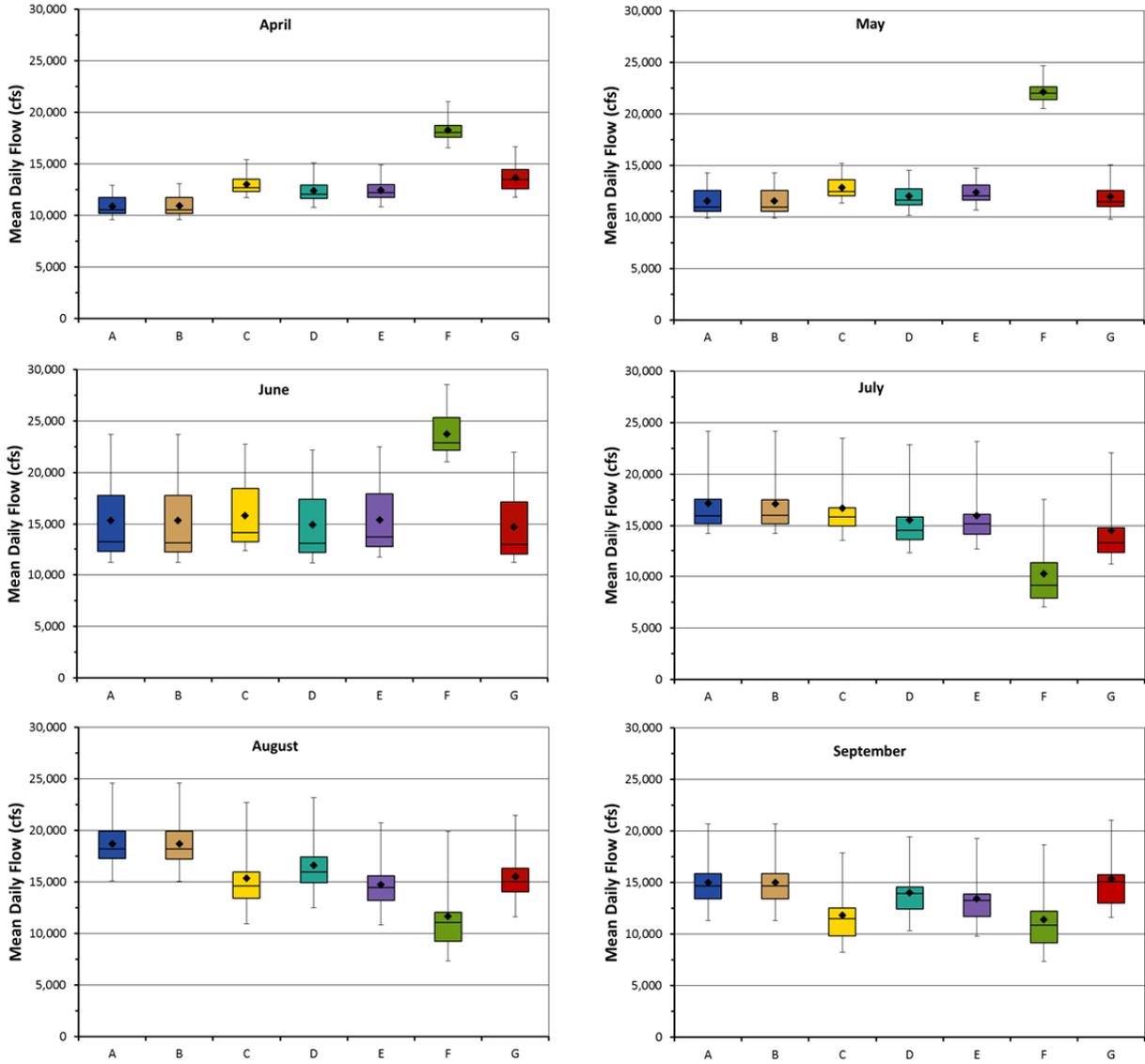
38 Similar to the pattern discussed above for mean daily flows, mean daily change would
39 vary the most among the scenarios in the months of June through September (Figure 4.2-4). This
40 pattern reflects the variability in monthly volume, which determines the level of amount of daily
41 change allowed under each alternative.
42

43 Mean daily change varies among the alternatives, ranging from 0 cfs (in all but the
44 months with HFEs) in the two steady flow alternatives (Alternatives F and G), to up to
45 12,000 cfs in Alternative B. Of the fluctuating flow alternatives (A–E), Alternative C has the
46 lowest mean daily change. Relative to Alternative A, mean daily change under Alternative D is



1
 2 **FIGURE 4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the Mean,**
 3 **Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology**
 4 **Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years**
 5 **within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median;**
 6 **lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker =**
 7 **minimum; upper whisker = maximum.)**

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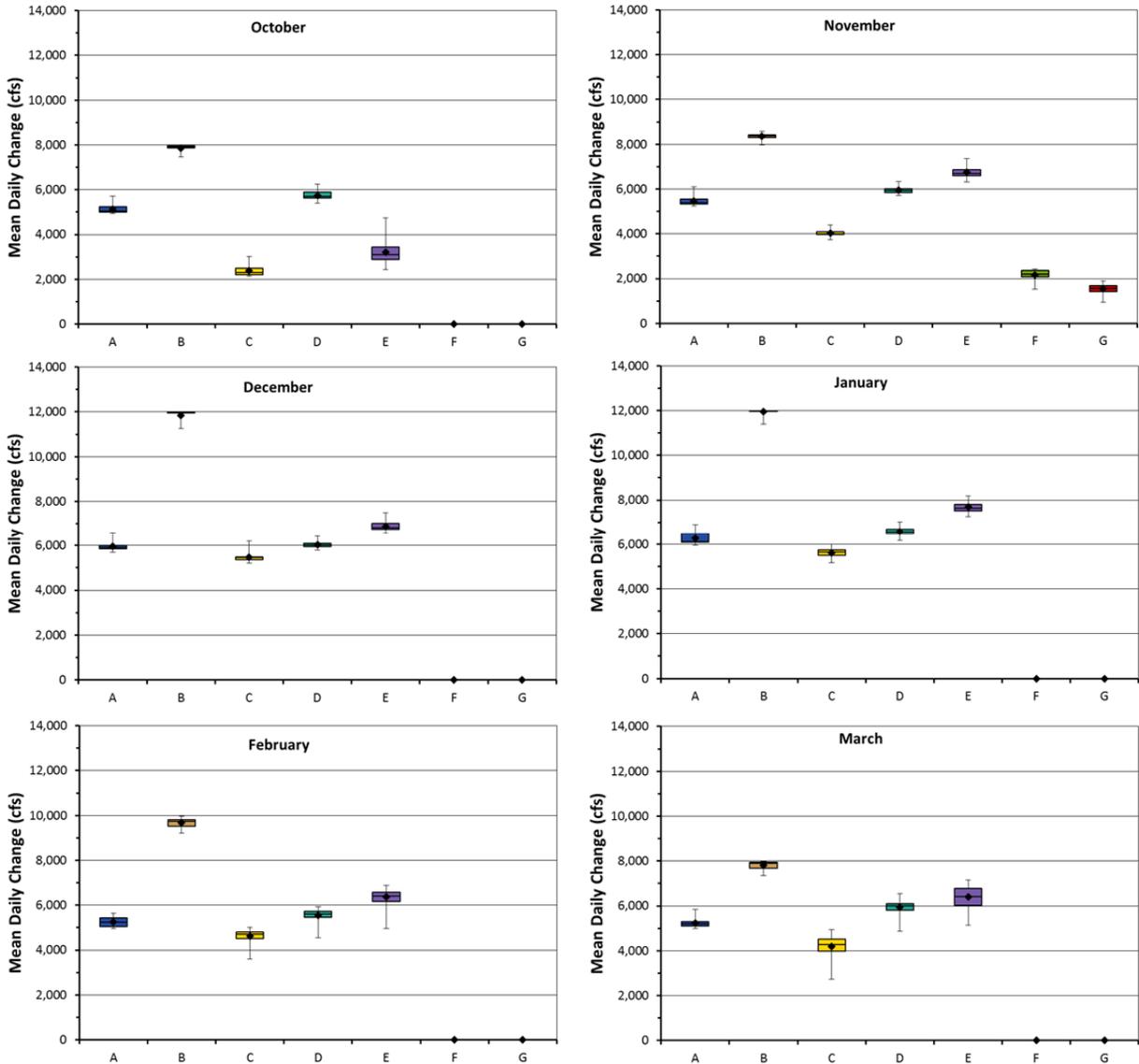
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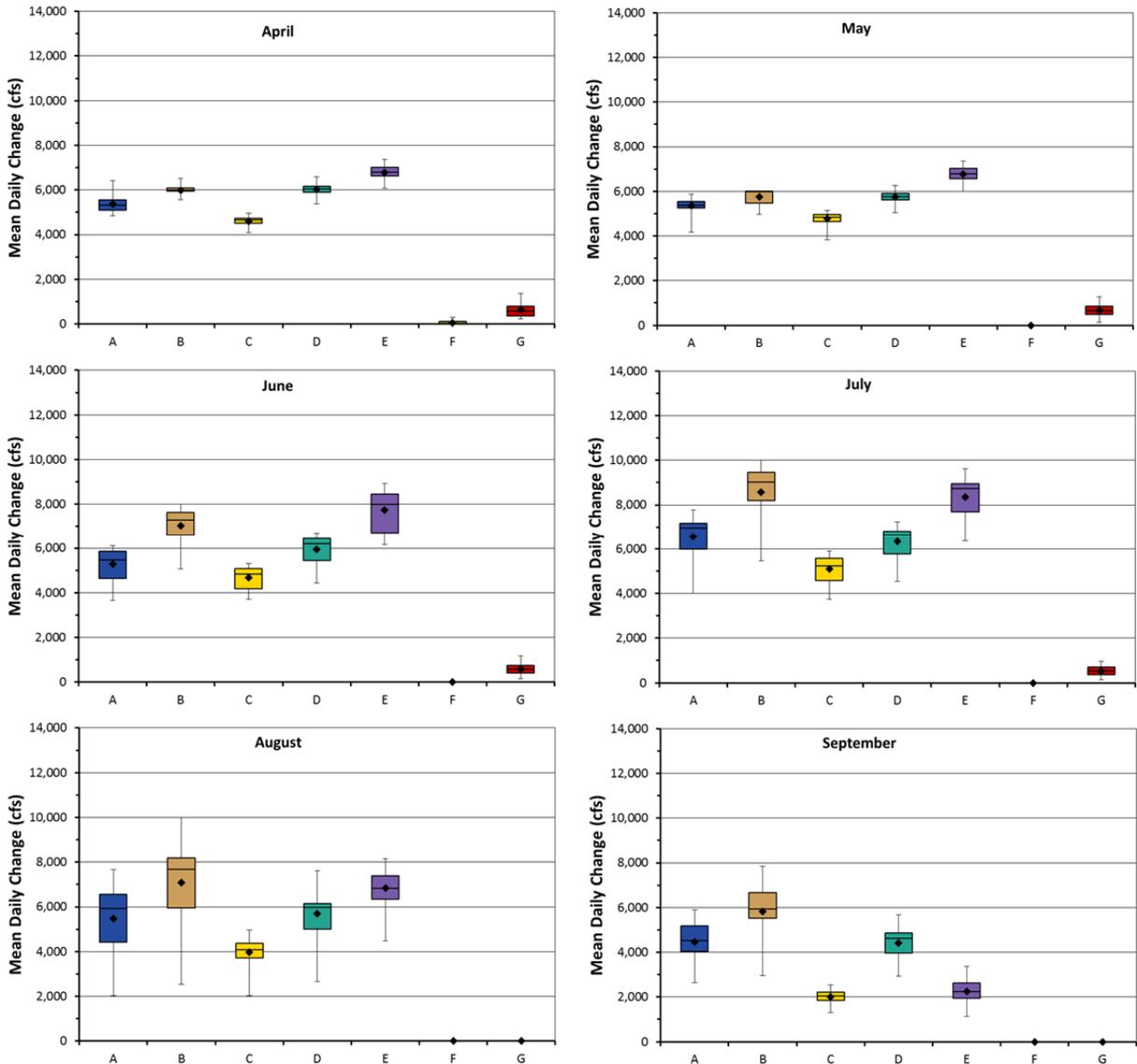
4

FIGURE 4.2-3 (Cont.)



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FIGURE 4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)



1

2 **FIGURE 4.2-4 (Cont.)**

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most similar; Alternatives C, F, and G are consistently lower; Alternative B is consistently
 6 higher; and Alternative E is higher in all months but September and October when load-
 7 following curtailment prior to HFEs would occur.

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Reservoir Elevations

11

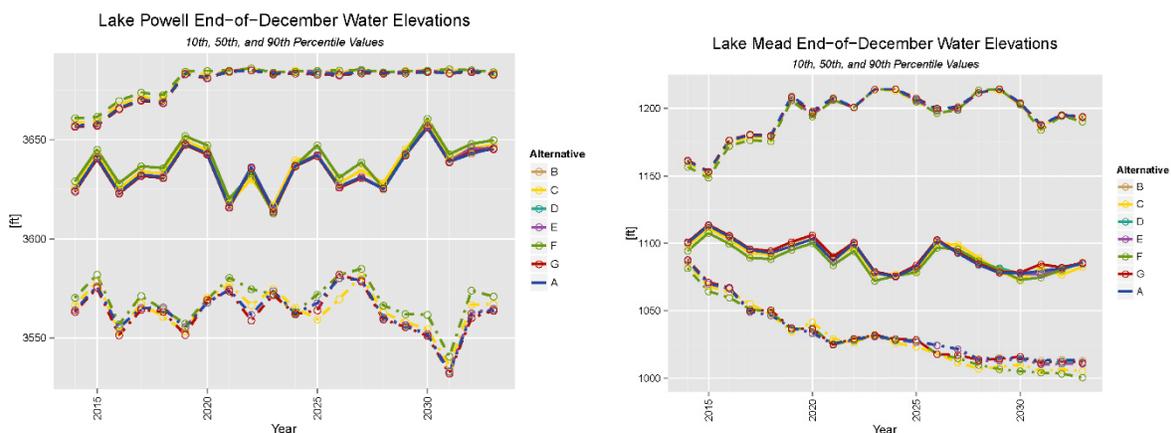
12

Lake Powell elevations are affected by potential future hydrology and Glen Canyon Dam
 13 operations. Lake Mead elevations are similarly affected by Glen Canyon Dam releases and
 14 Hoover Dam operations (including those related to meeting downstream water delivery
 15 obligations).

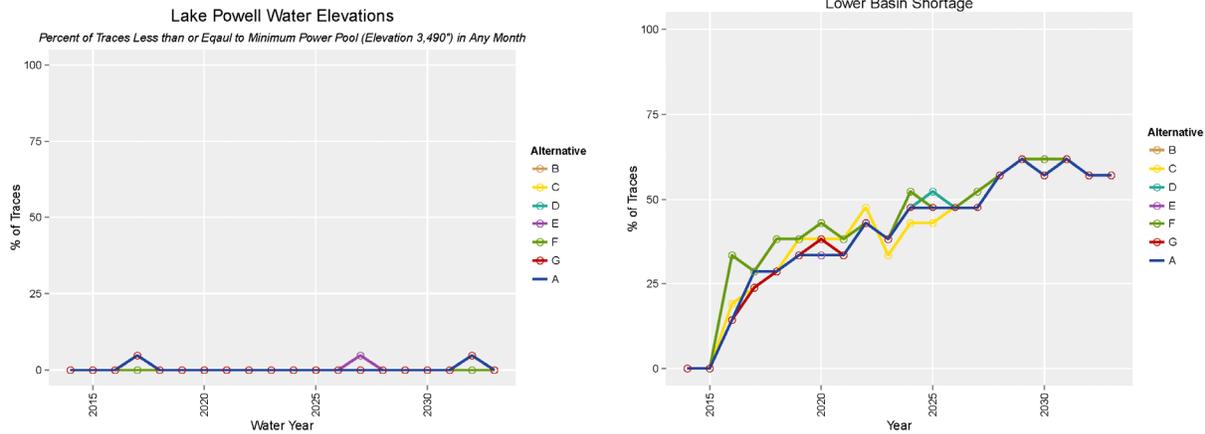
1 The elevations of Lake Powell and Lake Mead are more affected by annual variation in
 2 inflow than by alternative. Figure 4.2-5 presents end-of-calendar year elevations for Lake Powell
 3 and Lake Mead at the 10th, 50th, and 90th percentiles for 21 different hydrology traces and the
 4 seven different alternatives. The plots show that uncertainty associated with annual variation in
 5 inflow (variation among years) creates a larger range of pool elevations than do the differences
 6 within years among alternatives. In addition, differences among alternatives are greater at the
 7 10th and 50th percentiles, corresponding to lower lake elevations and drier hydrology.
 8 Differences at the 90th percentile, which corresponds to higher lake elevations and wetter
 9 hydrology, are minimal across all alternatives.

10
 11 The percentage of traces with Lake Powell falling below 3,490 ft (modeled minimum
 12 power pool) and the percentage of traces with Lower Basin shortages are shown in Figure 4.2-6.
 13 The probability of these conditions occurring is more affected by annual variation in inflow than
 14 by alternative. For Lake Powell elevations, all alternatives show very similar percentages for
 15 elevations that are $\leq 3,490$ ft. The percentage of traces ranges between 0 and 5 and remains
 16 relatively constant throughout the 20-year period. Typically, alternatives that show differences
 17 from Alternative A are due to an alternative releasing more or less water from October through
 18 March (the typical low elevation months). Alternatives that release less water in this period will
 19 have a lower probability of falling below 3,490 ft (e.g., Alternative F reduces the probability in
 20 2017 and 2032).

21
 22 For Lower Basin shortages pursuant to the applicable provisions of the 2007 Interim
 23 Guidelines (i.e., when Lake Mead’s elevation is projected to be at or below 1,075 ft on
 24 January 1), the percentages are also similar across alternatives, though with slightly more
 25 variability than with the Lake Powell minimum power pool. The percentage of traces with Lower
 26 Basin shortages generally increases over the 20-year period, ranging from zero in the first years
 27 of the period to nearly 62% of traces near the end of the period. The greatest difference across all
 28 alternatives is 19% in any given year. The October through December release from Lake Powell
 29 is the largest contributing factor in differences between Alternative A and the other alternatives.
 30
 31



32
 33 **FIGURE 4.2-5 Lake Powell (left) and Lake Mead (right) End of Calendar Year Pool**
 34 **Elevation for 21 Hydrology Traces and Seven Alternatives**



1
 2 **FIGURE 4.2-6 Percentage of Traces below Lake Powell’s Minimum Power Pool (elevation**
 3 **3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for**
 4 **21 Hydrology Traces and Seven Alternatives**

5
 6
 7 Alternatives that release less water in October through December show higher chances of
 8 shortages in the Lower Basin (e.g., Alternative F).

9
 10
 11 **Water Delivery**

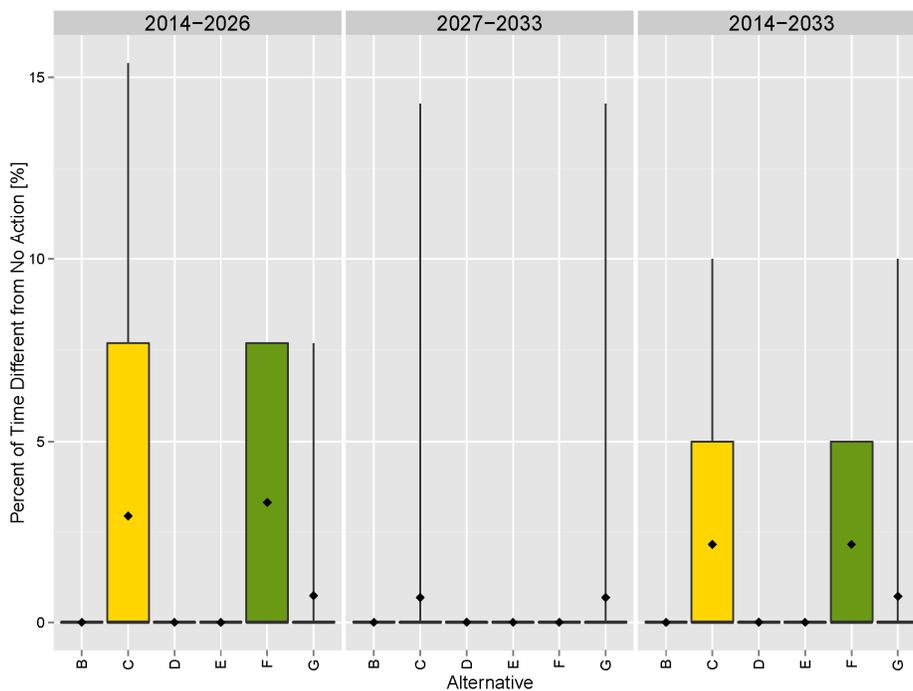
12
 13 The water delivery resource goal is to ensure water delivery to the communities and
 14 agriculture that depend on Colorado River water consistent with applicable determinations of
 15 annual water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado
 16 River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines
 17 for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. Note
 18 that all alternatives must meet these legal requirements.

19
 20 To evaluate potential differences among alternatives related to water delivery, the
 21 following metrics were calculated:

- 22
 23 • Frequency of deviation from Alternative A with regard to Lake Powell annual
 24 operating tier as specified by the 2007 Interim Guidelines,
 25
 26 • Probability over time of Lake Powell being in each operating tier as specified
 27 in the 2007 Interim Guidelines, and
 28
 29 • Frequency and volume of exceptions to meeting the annual release target
 30 volumes specified by the 2007 Interim Guidelines.

31
 32
 33 **Frequency of Deviation from Alternative A with Regard to Lake Powell Annual**
 34 **Operating Tier as Specified by the 2007 Interim Guidelines.** The frequency of deviation from

1 Alternative A with regard to Lake Powell annual operating tier pursuant to the 2007 Interim
 2 Guidelines is shown in Figure 4.2-7. This frequency was calculated as the number of years in
 3 which an alternative was modeled to be in an operating tier that is different from the modeled
 4 operating tier of Alternative A for the same year and trace combination divided by the total
 5 number of years (420 years for the 20-year period). For 2014–2026, the operating tiers pursuant
 6 to the 2007 Interim Guidelines were used; for 2027–2033, the operating tiers were defined as
 7 either an 8.23-maf release or a release greater than 8.23 maf.⁴ Operations under most of the
 8 alternatives do not result in a different operating tier from that under Alternative A. Of those
 9 alternatives that do show differences, the percentage of time in a different tier ranged from
 10 0 to 15.4%. Alternatives with an October through December release volume other than 2,000 kaf
 11 occasionally result in a different operating tier from Alternative A. Of the alternatives,
 12
 13



14

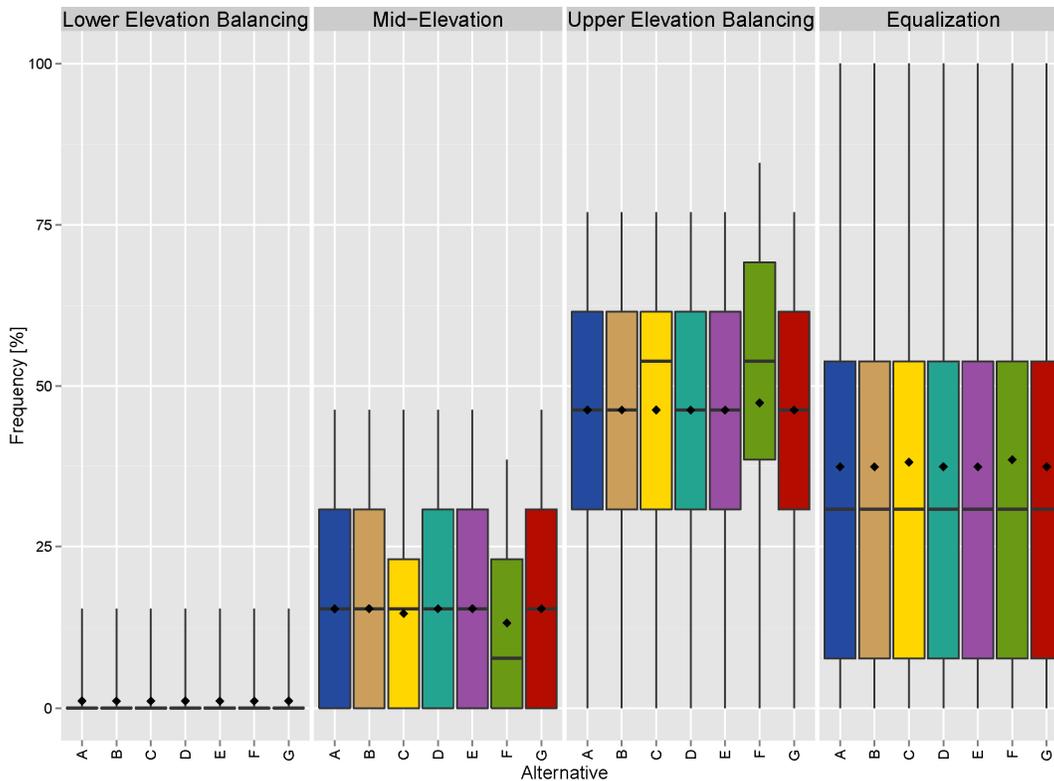
FIGURE 4.2-7 Percentage of Time in Different Operating Tier than Alternative A (The percentage of time in a different operating tier than the No Action Alternative is calculated for each trace and time period. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

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⁴ Under the 2007 Interim Guidelines, Lake Powell operates in four possible operating tiers through a full range of reservoir elevations and releases. The Interim Guidelines are in place through 2026 and include a provision that beginning no later than December 31, 2020, the Secretary of Interior shall initiate a formal review for purposes of evaluating these Guidelines. It is unknown what the outcome of the review will be, including whether or how new guidelines will be implemented. Unless new guidelines are implemented, after 2026, Lake Powell will revert back to the Interim Guidelines No Action Alternative with tiers defined as either an 8.23-maf release or a release greater than 8.23 maf.

1 Alternative C is in a different operating tier most frequently, an average of 2.1% of the time
 2 during the 20-year LTEMP period. If an alternative is in a different operating tier one year, it is
 3 more likely to be in a different operating tier than Alternative A in a following year, and the
 4 difference in a year-by-year comparison can cascade through the end of the period. It should be
 5 noted that in all instances, all alternatives implement the operating rules of the 2007 Interim
 6 Guidelines through 2026, but still show potential differences in operating tier.
 7
 8

9 **Probability over Time of Lake Powell Being in Each Operating Tier as Specified in**
 10 **the 2007 Interim Guidelines.** Figures 4.2-8 and 4.2-9 show the frequency of occurrence for
 11 Lake Powell operating tiers for each alternative during (Figure 4.2-8) and after (Figure 4.2-9) the
 12 interim period. The plots indicate that the frequency of each of the tiers is very similar across all
 13 alternatives, evidenced by the interquartile, minimum, and maximum values as well as the
 14 median and mean values. For all alternatives, the Upper Elevation Balancing Tier is the most
 15 common, followed by the Equalization Tier, then the Mid-Elevation Release Tier, and, lastly, the
 16 Lower Elevation Balancing Tier. Similar consistency across alternatives is evident in the period
 17 2027–2033.
 18
 19



20
 21 **FIGURE 4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under**
 22 **Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean;**
 23 **horizontal line = median; lower extent of box = 25th percentile; upper extent of**
 24 **box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)**

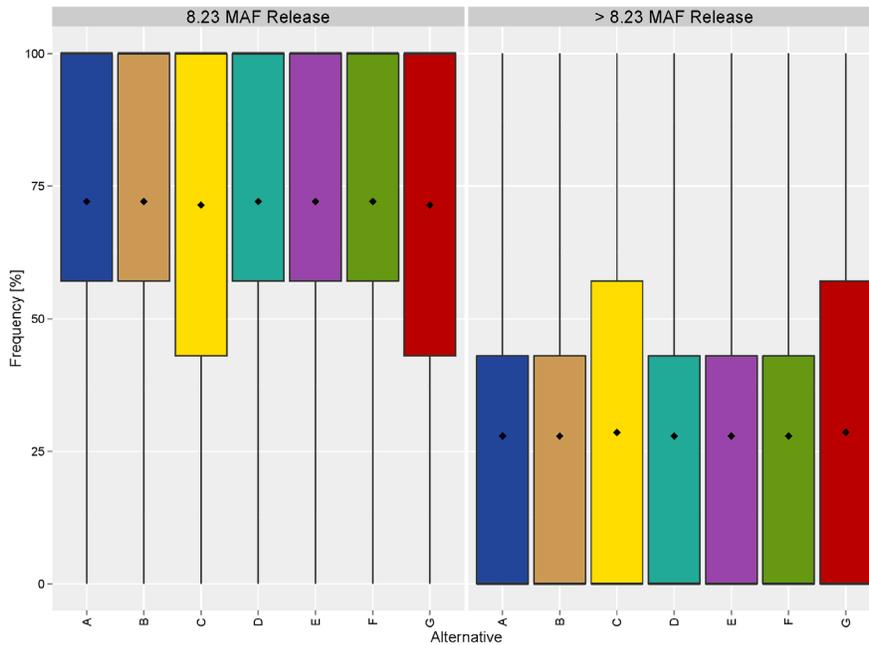
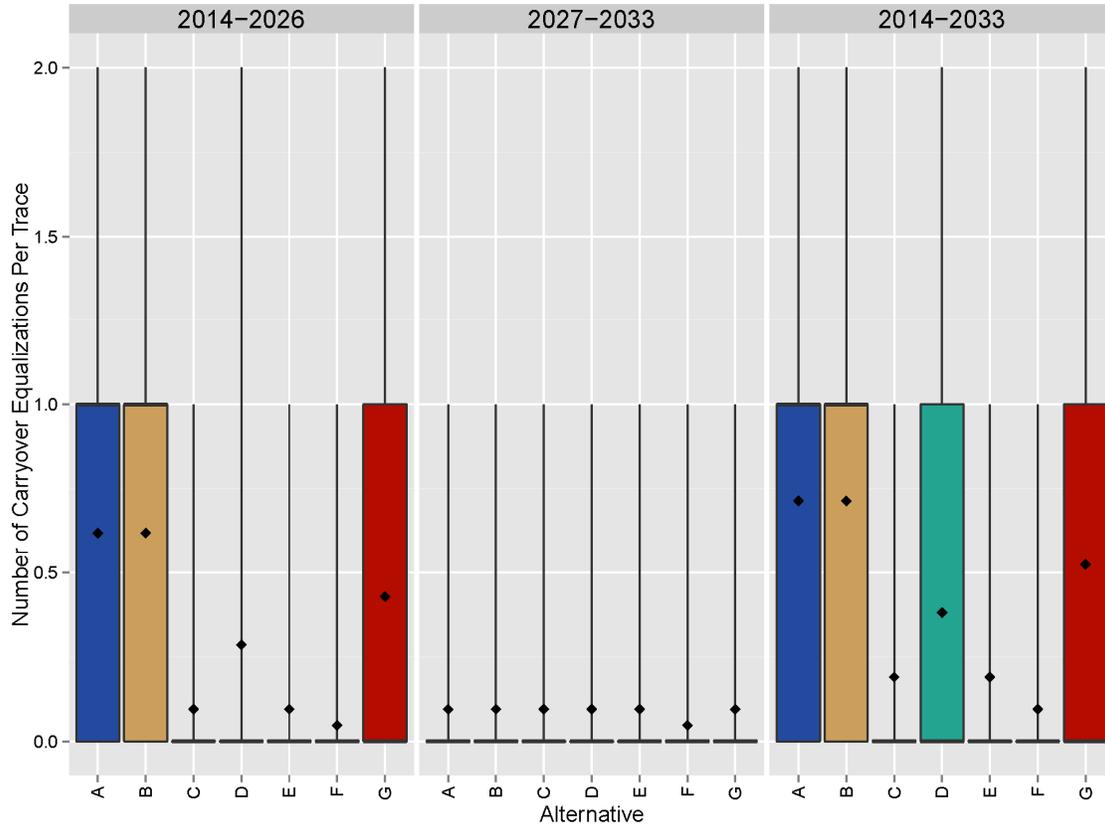


FIGURE 4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Frequency and Volume of Exceptions to Meeting the Annual Release Target Volumes Specified by the 2007 Interim Guidelines. The frequency (Figure 4.2-10) and volume of exceptions to meeting the annual release target volumes specified by the Interim Guidelines are shown below. The 2007 Interim Guidelines were developed with an operational goal of meeting the annual release target volume specified by the Interim Guidelines fully within a water year – that is, projected releases are to be achieved as nearly as is practicable by the end of each water year. Any instances of not meeting the specific release volume under the Interim Guidelines by the end of the relevant water year are due to physical constraints of being able to pass the full equalization volume through the powerplant turbines by the end of the water year, potentially resulting in annual releases extending beyond the water year. For modeling purposes, if it is not possible to fully equalize by the end of the water year, the remaining volume necessary to fully equalize is computed at the end of September; this volume is added to be immediately released as the initial portion of the next water year’s release. Again, for modeling purposes, this metric identifies the frequency and volume of annual releases extending beyond the water year. In these instances, the remaining volume was released as soon as physically possible (i.e., starting in October). Water would be released from Lake Powell up to full powerplant capacity until the annual release extending beyond the water year has been released in addition to the normal releases. In the modeling performed for this DEIS, all instances of annual releases extending beyond the water year were able to fully equalize within 3 months after the end of the water year and did not affect the operating tier for the next water year. The average number of years with annual releases extending beyond the water year in any 20-year trace is less than 1 for



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FIGURE 4.2-10 Frequency of Occurrence of Annual Releases Extending Beyond the Water Year per 20-Year Trace for Each of the Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

all alternatives, but ranges from 0 to 2. For most action alternatives (except for Alternative B), the average number of years with annual releases extending beyond the water year is less than under Alternative A. In addition, Alternatives C, E, and F reduce the maximum number of annual releases extending beyond the water year per trace from 2 to 1.

The volume of annual releases extending beyond the water year is also similar across alternatives. Across all alternatives, most of the volumes are 0 kaf, with the majority of the remaining volumes less than 500 kaf, and a handful of occurrences ranging up to 2,000 kaf of in 1 year. For the action alternatives, the volumes of annual releases extending beyond the water year are generally less than, though sometimes equal to, those under Alternative A. (See Appendix D for detail.)

4.2.2.2 Water Quality

This section discusses the general results of the water quality analyses and focuses on impacts on water temperature and salinity. Overall, there is little difference expected in water

1 quality among the different alternatives because annual volumes are the same for all alternatives
2 and the monthly and daily flow characteristics of alternatives do not vary drastically; any small
3 changes are expected to be comparable across all alternatives.
4

6 **Water Temperature**

7
8 This section presents a quantitative description of the modeled temperatures and overall
9 trends (e.g., seasonal changes) within and among the alternatives. More detailed analysis, as it
10 relates to specific resources, is provided within the applicable resource sections.
11

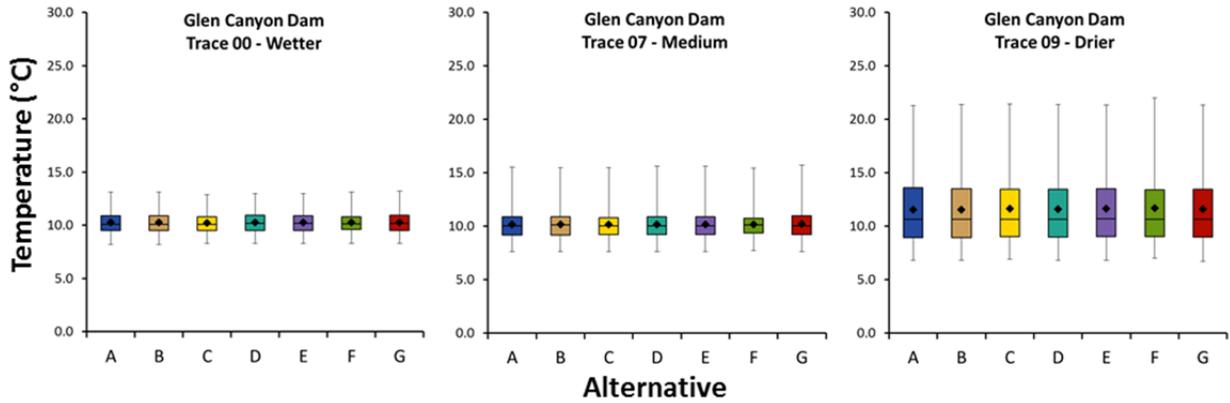
12 In general, Glen Canyon Dam operations under the various alternatives are not expected
13 to significantly affect Lake Powell reservoir water quality parameters; however, the dam outlet
14 temperature and thermocline location may be a factor in determining effects on water quality
15 downstream.
16

18 **Lake Powell**

19
20 As described in Section 3.3.3.2, Glen Canyon Dam release temperatures are highly
21 dependent on the position of the penstocks (i.e., elevation 3,470 ft) relative to the surface of
22 Lake Powell. In general, when lake surface elevations are high, releases tend to be cooler
23 because they originate deeper in the lake relative to the surface of the reservoir (e.g., from within
24 the hypolimnion). On the other hand, when lake surface elevations are low, withdrawals tend to
25 be warmer because they originate closer to the surface (i.e., from the metalimnion or upper
26 hypolimnion). Regardless of the alternative analyzed, temperature and elevation are highly
27 correlated.
28

29 Examination of the modeling results for effects of alternative operations on release
30 temperatures indicated that annual inflow volume to Lake Powell had a greater influence on the
31 release temperature than the operational differences in monthly and daily flows. Under drought
32 conditions, such as those seen recently (e.g., 2005–2010), release temperatures tend to be
33 consistently higher because reservoir elevations are generally low and releases originate closer to
34 the lake surface. However, during extreme drought, the elevation of Lake Powell may drop
35 below the minimum power pool elevation of 3,490 ft AMSL. If this occurs, releases cannot be
36 made from the powerplant penstocks and are instead routed through the river outlet tubes located
37 3,374 ft AMSL. Because water at the level of the river outlet tubes is generally colder due to its
38 depth, release temperatures could drop to less than 10°C. If the reservoir elevations were to drop
39 farther, closer to the elevation of the river outlet tubes, the releases would again gradually warm
40 (Reclamation 2007a).
41

42 Figure 4.2-11 compares the mean temperatures of water released from Glen Canyon Dam
43 for wet, medium, and dry hydrology traces. These figures illustrate how little temperature
44 variation there is among the seven LTEMP alternatives (within any given trace) compared to the
45 much larger variation across the traces. For example, the minimum, maximum, and mean values
46 for modeled temperature at Glen Canyon Dam vary less than 0.3°C, 0.7°C, and 0.2°C,



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FIGURE 4.2-11 Comparison of Mean Water Temperatures for Representative Wetter, Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

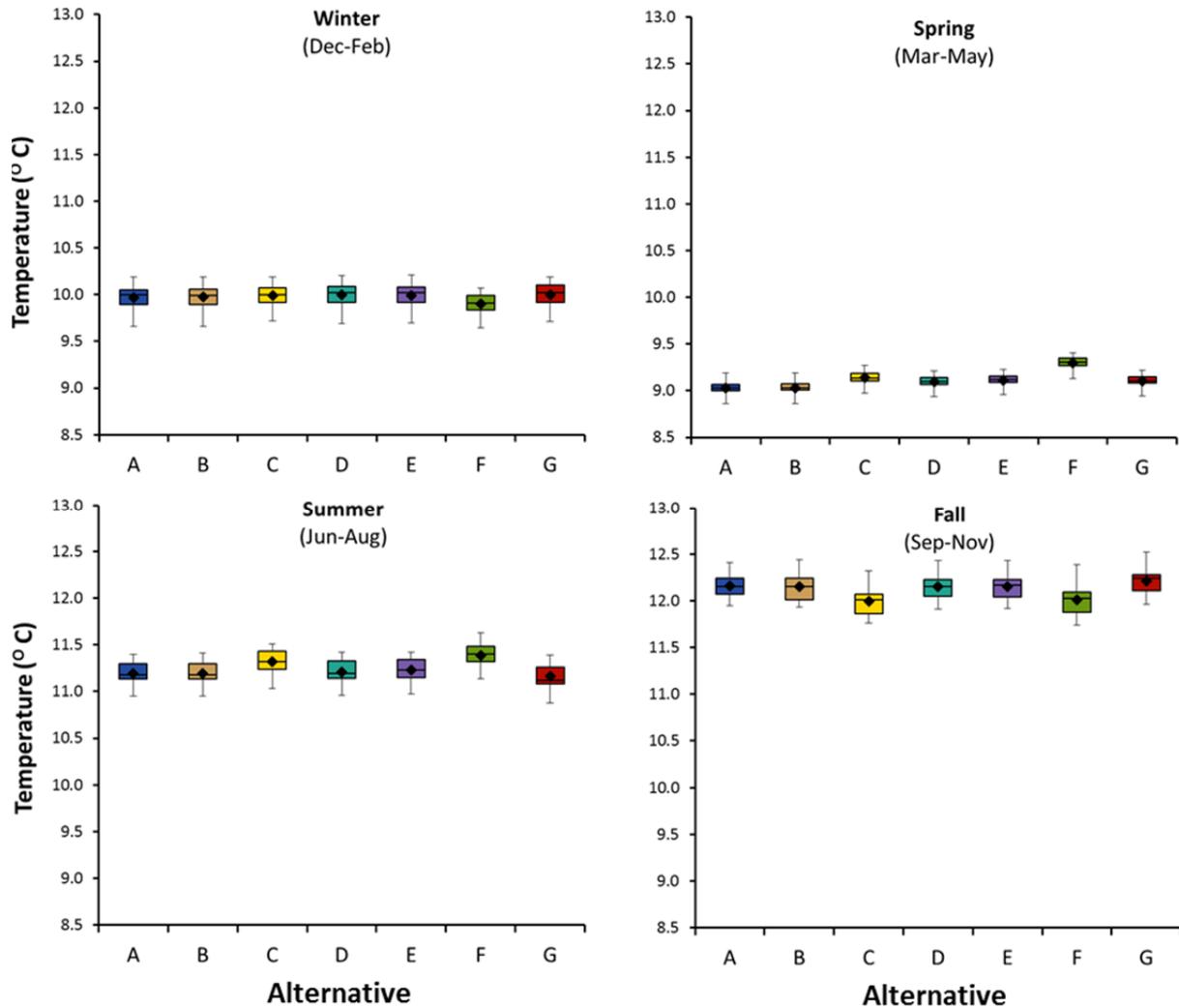
respectively, among the alternatives for any given trace. However, across hydrology traces the minimum, maximum, and mean values vary over a range of approximately 1.5°C, 8.8°C, and 1.5°C, respectively.

Drier hydrology traces exhibit greater variation in temperature values and more pronounced differences among alternatives, although the actual differences in means are still quite small (i.e., less than 0.2°C). This is because drier traces have lower overall inflow volumes and consequently lower reservoir levels in most years. The released water associated with lower lake elevations is drawn from closer to the surface, where it is more sensitive to atmospheric conditions (e.g., air temperature and solar radiation). However, the release water associated with higher lake elevations (resulting from higher cumulative inflow volumes) tends to be drawn from deeper in the hypolimnion, which exhibits a more stable temperature profile. Therefore, operational differences that have nearly negligible perceived impacts on temperature at larger water volumes (i.e., wetter traces) can become more pronounced during drier traces.

Figure 4.2-12 illustrates mean seasonal⁵ release temperatures at Glen Canyon Dam, aggregated across the 21 hydrology traces for the modeled 20-year time period. Overall, the seasonal temperature ranges are similar across alternatives.

The minimum mean release temperatures occur in the spring, with aggregated mean values ranging from 9.0 to 9.3°C, depending on alternative. The lower end of this range is characteristic of Alternatives A and B. The top end of this range is associated with Alternative F, possibly because the reservoir elevation is lower by May after sustained higher releases in March and April. Considering all traces across the entire modeled time period, the full range of mean

⁵ For the purposes of this discussion, seasonal temperatures are represented by 3-month periods representing the standard meteorological seasons: December–February for winter; March–May for spring; June–August for summer; and September–November for fall.



1

2 **FIGURE 4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives**
 3 **(Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile;**
 4 **upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)**

5
 6

7 spring release temperatures varied from around 8.8 to 9.5°C depending on alternative. The
 8 bottom of this range is generally representative of wetter traces (i.e., higher reservoir elevations),
 9 and the top of this range is generally represented by drier traces (i.e., lower reservoir elevations).

10

11 The peak mean release temperature occurs during the fall, with aggregated means ranging
 12 from 12.0 to 12.2°C, depending on alternative; however, there are no significant differences
 13 among alternatives in mean release temperature even in the fall. Considering all traces, the full
 14 range of mean fall release temperatures varied from around 10.7 to 14.3°C, depending on
 15 alternative. As with spring temperatures, the bottom of the fall range is generally representative
 16 of wetter traces (i.e., higher reservoir elevations), and the top of this range is generally
 17 represented by drier traces (i.e., lower reservoir elevations).

18

1 Glen Canyon Dam release temperatures (for all alternatives) are lower in spring than in
2 winter, and lower in summer than in fall. This difference is a result of the lag time associated
3 with warming and cooling of Lake Powell (refer to Section 3.3.3.1 for further information on
4 Lake Powell hydrology).

5
6
7 ***Colorado River between Glen Canyon Dam and Lake Mead***
8

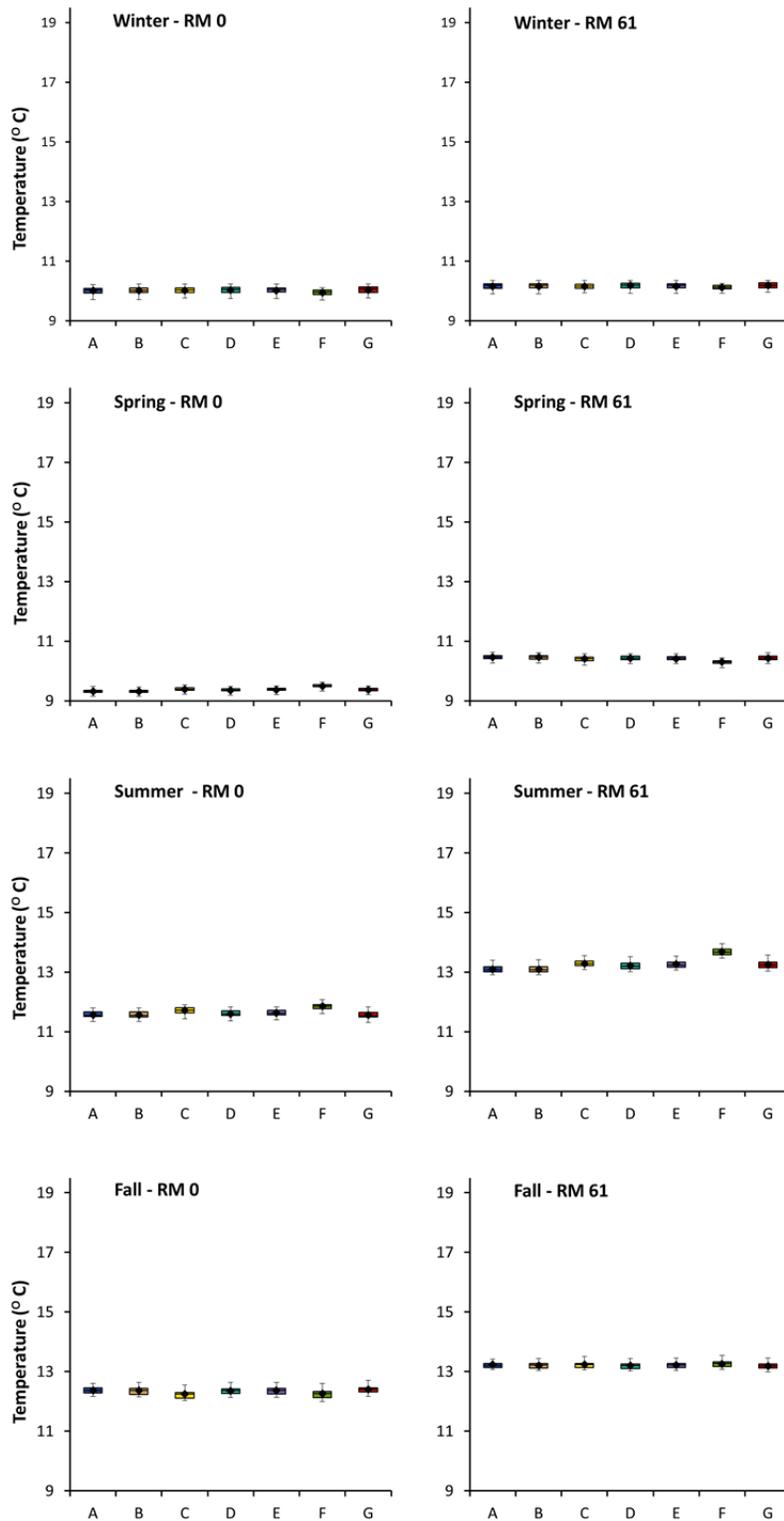
9 Once released from the dam, typically warmer air temperatures regulate river
10 temperature. Consequently, the warmer spring and summer months see significant downstream
11 warming while colder winter and fall months have much less downstream warming, and perhaps
12 even downstream cooling (Voichick and Wright 2007). Tributaries, such as the Little Colorado
13 River (river mile [RM] 61), provide warmer inflows in the summer and cooler inflows in the
14 winter (refer to Section 3.3.4.2 for additional details related to Colorado River water
15 temperatures between Glen Canyon Dam and Lake Mead.)
16

17 Comparisons of the seasonal trends in river temperatures among the seven LTEMP
18 alternatives are illustrated in Figure 4.2-13 at locations between Glen Canyon Dam (RM 0) and
19 Diamond Creek (RM 225). Temperatures presented in these figures represent modeled values
20 aggregated across the 21 hydrology traces. In general, projected temperatures vary due to three
21 factors: release volume, release temperature, and downstream meteorology and hydrology. The
22 rate at which the water released from a reservoir approaches ambient air temperature as it travels
23 downstream depends on these factors as well (Reclamation 2007a).
24

25 Overall, mean seasonal temperatures increase as water moves downstream. Winter river
26 temperatures are the coldest of any season. Mean winter temperatures ranged from 9.7 to 10.2°C
27 at RM 0 (Lees Ferry), 9.9 to 10.4°C at RM 61 (Little Colorado River), 10.2 to 10.6°C at RM 157
28 (Havasu Creek), and 10.4 to 10.8°C at RM 225 (Diamond Creek). These data also indicate that
29 within any given alternative, there is a very small longitudinal gradient (i.e., at most a 0.5–0.7°C
30 difference for mean; 1.0–1.1°C difference across the full range of values) between the mean
31 temperatures at the Glen Canyon Dam outlet and Diamond Creek during the winter.
32

33 For all alternatives, significant downstream warming (i.e., between 6.0 and 7.2°C
34 difference for mean; 6.8–8.1°C difference across full range of values) is expected in the summer.
35 Average summer temperatures are the warmest of any season, ranging from 11.3 to 12.1°C at
36 RM 0, 12.9 to 14.0°C at RM 61, 15.3 to 17.0°C at RM 157, and 16.9 to 19.2°C at RM 225. More
37 details related to temperature values and ranges for each of the seven LTEMP alternatives are
38 presented in Section 4.2.3.
39

40 A number of experimental actions (described in detail in Section 2.3) would be
41 incorporated into many of the LTEMP alternatives. Operational actions such as HFEs, TMFs,
42 low summer flows, and sustained low flows for benthic invertebrate production may have
43 noticeable impacts on water temperature at the Glen Canyon Dam outlet and downstream. Past
44 experimental events and water temperature models have provided the following insights into
45 water temperature response to these experimental actions.
46



1
2
3
4
5
6

FIGURE 4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

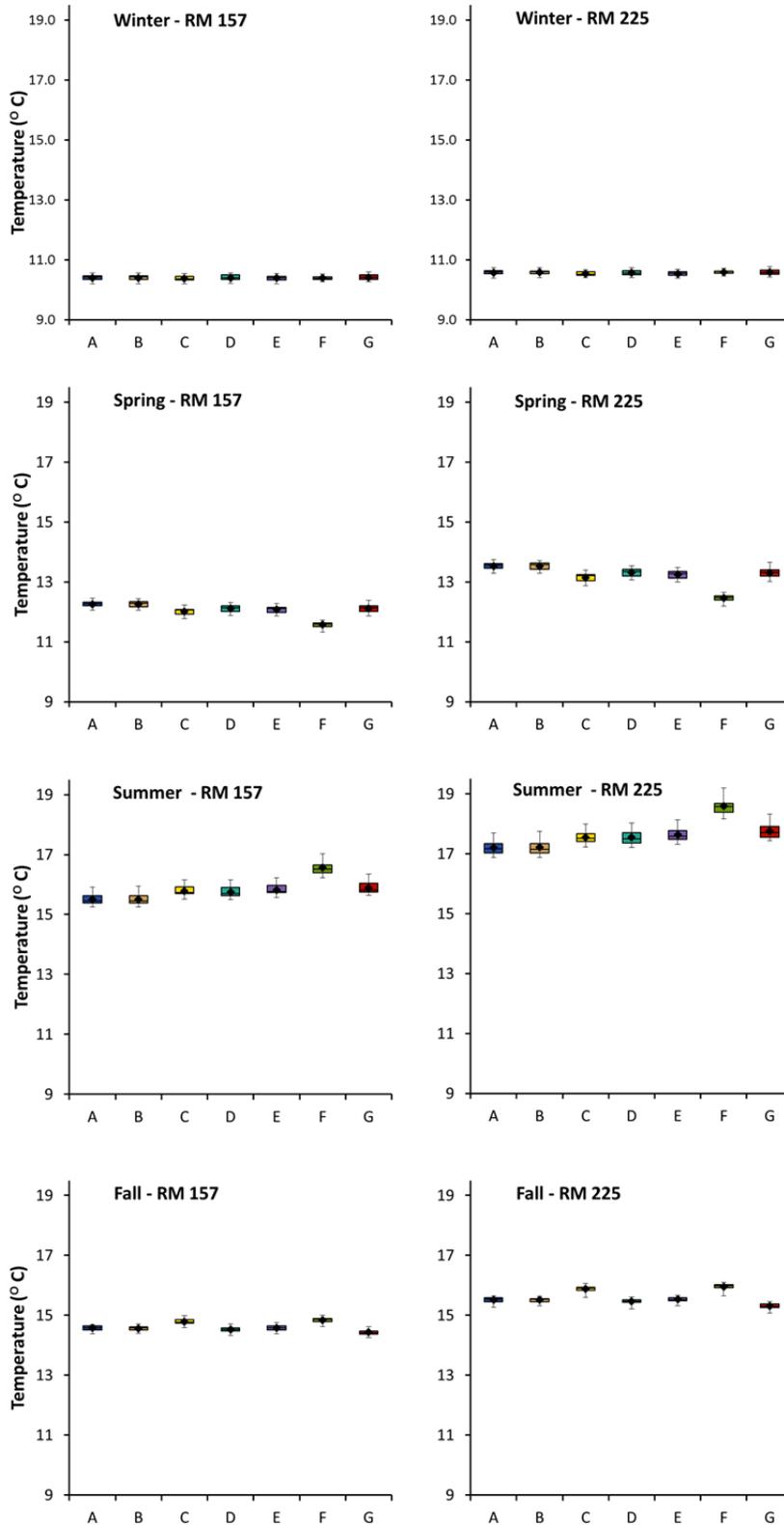


FIGURE 4.2-13 (Cont.)

1

2

3

1 The magnitude, duration, and seasonal timing of an HFE vary according to sediment
2 input from the Paria River and other resource conditions. In the limited number of HFEs run and
3 analyzed from 1996 to 2011 (i.e., fall of 1996, 2004, and 2008; spring of 2008), effects on water
4 temperature have been observed to be minor and short-term, and to result in slight reductions in
5 downstream water temperature (Vernieu et al. 2005; Reclamation 2011b). Modeling conducted
6 for this DEIS reflects these observations. In general, fall end-of-month temperatures are
7 approximately 1°C higher at Diamond Creek (RM 225) in years without an HFE event than in
8 comparable fall seasons with HFEs. Downstream temperature cooling is similarly expected for
9 spring HFEs, although temperature decreases are expected to be smaller (end-of-month
10 temperatures 0.1–0.5°C cooler). Considering that the November 2012 HFE (releasing
11 approximately 42,000 cfs for 24 hr) and the November 2013 HFE (releasing nearly 35,000 cfs
12 for 96 hr) took only 55 and 54 hr, respectively, to reach Pearce Ferry (i.e., RM 279) (NPS 2012e,
13 2013j), any warming would be expected to be small and of short duration.

14
15 If very large amounts of sediment are input by the Paria River, HFEs may have durations
16 of up to 336 hr under Alternative G and 250 hr under Alternative D. Modeling indicates that,
17 when considering HFEs of similar magnitude (occurring in the fall), downstream warming
18 increases slightly and gradually as the duration of the HFE increases. For example, the difference
19 between the downstream warming of a 48-hr and 336-hr HFE (both at 45,000 cfs) was less than
20 1°C.

21
22 TMFs have not been tested in the Colorado River; therefore, water temperature effects of
23 these flows are uncertain. Overall, the magnitude of flow changes for TMFs are smaller
24 compared to HFEs. As a result, perceptible temperature changes at the dam or downstream are
25 not expected. For example, a TMF modeled to run for 72 hours at a steady flow of 20,000 cfs
26 does not exhibit noticeable effects on modeled water temperatures.

27
28 Experimental low summer flows could occur under Alternatives C, D, and E. Low
29 summer flows are run at approximately 8,000 cfs for the months of July, August, and September.
30 Modeled low summer flows show similar water temperatures just downstream of the dam, with
31 slightly higher downstream warming, when compared to similar conditions without low summer
32 flows. This is because lower velocity flows have a higher surface-area-to-volume ratio
33 (compared to high flows) and greater exposure time with the ambient air, which facilitates water
34 warming through solar radiation and atmospheric heat exchange (Vernieu et al. 2005). When
35 considering individual model traces, variations in downstream temperatures were generally
36 greatest in July (nearly 3°C warmer for low summer flows) and least in September (about 1°C
37 warmer for low summer flows), with August falling in the middle (approximately 2°C warmer
38 for low summer flows).

39
40 Sustained low flows for benthic invertebrate⁶ production are one of the experimental
41 modifications to base operations for Alternative D that could be tested during the LTEMP
42 period. For this experiment, flow on Saturdays and Sundays of May through August would be
43 held steady at the minimum monthly flow. These stable weekend flows would be tested to

⁶ Animal without a backbone or spinal column, usually replaced by a hard exoskeleton or shell. Examples include insects, worms, crustaceans, snails, or clams.

1 determine whether they improved invertebrate production. This operational action increases the
2 mean daily flows during the weekdays. Water temperature modeling indicates that release
3 temperature would change little (e.g., $\pm 0.01^{\circ}\text{C}$), and warming at downstream locations during the
4 summer, as indicated by maximum temperature, would be less than 1°C (0.03°C at the
5 confluence with the Little Colorado River [RM 61] and 0.12°C at Diamond Creek [RM 225]).
6
7

8 **Lake Mead**

9

10 Potential water quality issues in Lake Mead were evaluated based on a concern expressed
11 by Southern Nevada Water Authority that water quality could be affected by significant shifts in
12 the temperature of Colorado River water reaching Lake Mead. The temperature of the water
13 determines its density and its position within the water column of Lake Mead. Warmer Colorado
14 River inflows would enter and flow through Lake Mead in the middle of the water column
15 (Tietjen 2014), and this could then have adverse impacts on bottom water oxygen concentrations,
16 effectively trapping below the inflow area low-DO water that does not mix completely and could
17 slowly expand down the lake.
18

19 Modeling was conducted by the Southern Nevada Water Authority on a selected set of
20 LTEMP alternatives (Alternatives A, E, and F) and years (2-year runs) that were considered to
21 represent the range of potential outcomes. Because Alternative F would produce the warmest
22 water temperatures of all alternatives in the summer, it was chosen as the potential worst case.
23 Modeling indicated there would be negligible differences in the distribution of areas of low DO
24 among modeled alternatives (Tietjen 2015).
25

26 HFEs were not shown to have measurable impacts on Lake Mead water quality. They are
27 expected to mix a portion of the low-DO water near the sediment-water interface up into the
28 water column near the inflow area to Lake Mead, and this should act to reduce (or possibly
29 eliminate) any observed low-oxygen problems (Tietjen 2014).
30
31

32 **Salinity**

33

34 The projected salinity concentrations presented in Figure 4.2-14 are the flow-weighted
35 annual means over the 20-year LTEMP period at Lees Ferry (no criteria established for this
36 location). The results assume continuation of existing and implementation of planned salinity
37 control programs and projects.
38

39 Under all alternatives, salinity would increase as water moves downstream. Mean
40 concentrations at Lees Ferry are 490 mg/L, with a full range from 468 to 508 mg/L considering
41 the entire modeled period across all seven LTEMP alternatives (Figure 4.2-14). Considering all
42 years individually, the differences in salinity concentrations among the different alternatives is
43 less than 2.5%.
44
45

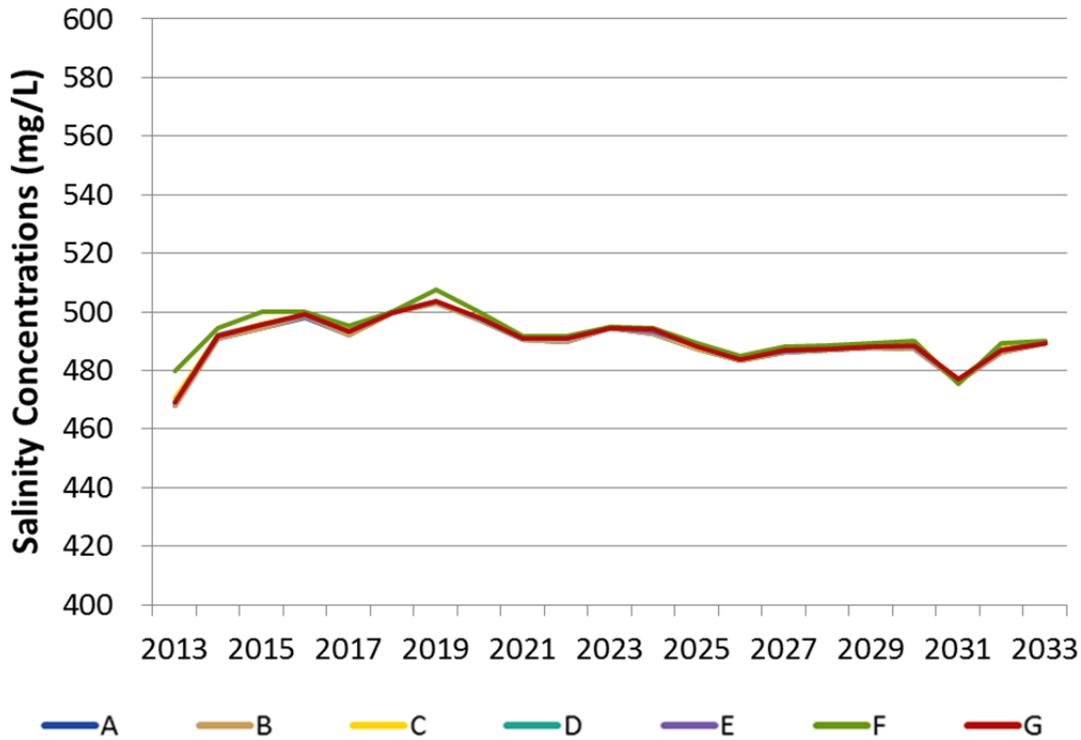


FIGURE 4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at Lees Ferry

Other Water Quality Parameters

No significant impacts on other water quality parameters (e.g., DO, nutrients, metals, and organics) are expected under any LTEMP alternative. In addition, research (Reclamation 2011b) has indicated that the potential effects of HFEs on other water quality parameters (e.g., turbidity and DO) below the dam would only be temporary, and any observed effects would recover quickly when lower flows returned (refer to Section 3.3.4.2 for more details on the effects of HFEs on water quality of the Colorado River below the Glen Canyon Dam).

With respect to turbidity, a positive correlation with tributary sediment input is also expected (refer to Section 3.3.4.2 for more information on the relationship between turbidity and suspended sediment). However, no impacts are expected because operations will not affect tributary sediment input, and, therefore, will not result in differences among the alternatives.

Although an increase in visitor use could result in an increase in the occurrence of pathogens, current National Park Service (NPS) regulations restrict the number of river boating trips that can be taken; a long waiting list exists for private boating permits and a large number of commercial passengers cannot be accommodated due to these restrictions. As a consequence, the numbers of angling and boating trips are not expected to change as a result of any of the alternatives, and no difference in pathogenic or disease-causing organisms is expected as a result of variation in the number of visitors. However, certain types of flow have been associated with local occurrences of high pathogenic bacterial counts. For example, low steady flows,

1 particularly during periods of high recreational use, can result in local areas of exceedances due
2 to the buildup of bacteria along the shoreline. Higher velocity or flood flows can act to mobilize
3 these bacteria harbored in streamside sediments from past recreational use, in effect, flushing out
4 areas of concern, but also temporarily increasing downstream bacteria counts. As a result,
5 alternatives with either low flows and/or high flows may lead to a higher potential for
6 contamination from bacteria and other pathogens and, thus, could increase the possibility of
7 health hazards associated with contaminated water. Years with low release volumes (<8.23 maf)
8 would have a higher probability of occurrence. The probability of this contamination occurring is
9 expected to be very low, and the effects would be localized for all alternatives. However, there
10 are potential differences among alternatives related to the occurrence of low flows and HFEs.
11 Alternatives C, D, E, and F all have low flows and frequent HFEs and could have a higher
12 potential for bacteria and pathogen contamination than Alternatives A and B. Alternatives F and
13 G have the highest potential (though still low), given the annual occurrence of steady flows and
14 frequent HFEs.

15 16 17 **4.2.3 Alternative-Specific Impacts**

18
19 The following sections describe the range of alternative-specific impacts on hydrology,
20 (i.e., reservoir releases and elevations, river flows) and water quality. Both water delivery
21 metrics and other system relevant conditions (e.g., reservoir elevations) are discussed for each
22 alternative. Each alternative was modeled using 21 different potential scenarios that accounted
23 for uncertainty in future hydrologic conditions. Figures 4.2-1 through 4.2-14 show the results for
24 all alternatives; plots comparing each action alternative to Alternative A can be found in
25 Appendix D.

26
27 The modeling predicted that inflow hydrology has the most effect on operating tier,
28 release volume, and resulting reservoir elevations, whereas the alternatives show smaller effects.
29 Differences among the LTEMP alternatives are expected to be negligible with regard to salinity,
30 turbidity, nutrients, DO, metals/radionuclides, or organic/other contaminants. As a result,
31 temperature and bacteria and pathogens are the only water quality parameters discussed in this
32 section. When analyzing the temperature differences between the LTEMP alternatives,
33 differences of less than 0.5°C are not regarded as significant because of the inherent temperature
34 variability observed in the natural environment, combined with the reported standard error
35 (i.e., less than 0.5°C) for the temperature model applied (Wright, Anderson et al. 2008). Thus,
36 only temperature differences greater than 0.5°C are explained in further detail.

37 38 39 **4.2.3.1 Alternative A (No Action Alternative)**

40
41 During the interim period (through 2026), Alternative A would operate at times within
42 each of the four operating tiers, at the following mean annual frequencies: Upper Elevation
43 Balancing Tier—46.2%; Equalization Tier—37.4%; Mid-Elevation Release Tier—15.4%; and
44 Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative A has annual
45 releases of 8.23 maf in an average of 72.1% of years and annual releases greater than 8.23 maf in
46 an average of 27.9% of years.

1 During wet years, Lake Powell may not always be able to fully equalize within the water
2 year, resulting in annual releases extending beyond the water year. For Alternative A, the mean
3 number of occurrences of annual release extending beyond the water year per 20-year trace is
4 0.7, with a range of 0 to 2 occurrences per 20-year period. The mean volume of annual release
5 extending beyond the water year is 248 kaf with a range from 0 to 2,021 kaf.
6

7 Under Alternative A, monthly reservoir releases are generally higher in December,
8 January, July, and August and lower in the other months. In the years 2014–2020, when HFEs
9 would be implemented under Alternative A, water may need to be reallocated from later months
10 in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet
11 minimum release requirements.
12

13 Lake Powell elevations would vary significantly with hydrology but would vary little by
14 alternative. Depending on hydrology, Lake Powell elevations can be anywhere in the full range
15 of operating elevations. Under Alternative A, the median elevation for Lake Powell at the end of
16 December was about 3,630 ft throughout the 20-year LTEMP period. End-of-December
17 elevations ranged from about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles,
18 respectively. Under Alternative A, this modeling showed two instances out of 420 (20 years and
19 21 traces) when Lake Powell would drop temporarily below the 3,490-ft minimum power pool.
20

21 Lake Mead elevations would also vary significantly with basin hydrology and the
22 resulting Lake Powell release, but would vary little by alternative. Depending on hydrology,
23 Lake Mead elevations can be anywhere in the full range of operating elevations. Under
24 Alternative A, the median elevation for Lake Mead at the end of December ranged from about
25 1,100 ft near the beginning of the period to about 1,080 ft near the end of the 20-year LTEMP
26 period. End-of-December elevations at the beginning of the period ranged from about 1,080 ft to
27 about 1,160 ft at the 10th and 90th percentiles, respectively, and from about 1,020 ft to about
28 1,210 ft near the end of 20-year LTEMP period. Under Alternative A, the percentage of traces
29 with Lower Basin Shortages is 0 for the first 2 years of the period, and then increases to 62% of
30 traces near the end of the 20-year period.
31

32 Mean monthly volume under Alternative A would be similar to current conditions and
33 would be highest during months with relatively high hydropower demand (December, January,
34 June, July, and August) when volume would range from approximately 670,000 to
35 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would be approximately 570,000 to
36 1,200,000 ac-ft in other months.
37

38 Mean daily flows under Alternative A also would represent no change from current
39 conditions, and would be highest in the higher volume months of December, January, June, July,
40 August, as well as September, when flows would range from approximately 11,200 to 24,600 cfs
41 under the scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to
42 14,400 cfs in other months.
43

44 Under Alternative A, the allowable daily range is dependent on monthly volume and
45 ranges from 5,000 to 8,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily
46 change would occur in December, January, July, and August, when mean daily change would

1 vary from about 2,000 to 7,800 cfs (Figure 4.2-4). In other months, mean daily change would
2 range from 2,600 to 6,400 cfs.

3
4 Seasonal temperature data and trends are provided in Table 4.2-2 for the seven LTEMP
5 alternatives as a function of distance downstream from RM 0 (i.e., Lees Ferry) through RM 225
6 (i.e., Diamond Creek). The minimum, maximum, and mean temperature data presented in these
7 figures represent values aggregated across the 21 hydrology traces over the 20-year LTEMP
8 period.

9
10 For Alternative A, mean winter temperatures are expected to warm the least, with a
11 difference of about 0.5°C (10.0–10.6°C) between the Lees Ferry and Diamond Creek locations.
12 Summer temperatures are expected to warm the most as they move downstream, with an
13 approximately 5.6°C (11.6–17.2°F) difference. Spring temperatures warm around 4.2°C
14 (9.3–13.5°C); fall temperatures warm about 3.1°C (12.4–15.5°C).

15
16 Under Alternative A, there would be no change from current conditions in the occurrence
17 of bacteria or pathogen contamination along shorelines. The expected probability of this
18 contamination occurring is very low, and would be localized and temporary.

19
20 In summary, Alternative A would result in no changes in current conditions related to
21 hydrology or water quality.

22 23 24 **4.2.3.2 Alternative B**

25
26 Alternative B would show little or no difference from Alternative A with regard to
27 operating tier, in almost every one of the 21 hydrology traces modeled. This is the smallest
28 difference among all of the action alternatives. Compared to Alternative A, Alternative B would
29 result in the same frequency of operating tiers, the same average number of occurrences of
30 annual releases extending beyond the water year, and the same volume of annual release
31 extending beyond the water year. In addition, the end-of-December elevations under
32 Alternative B for Lake Powell and Lake Mead would be identical to those under Alternative A.

33
34 Under Alternative B, monthly reservoir releases would be identical to those of
35 Alternative A. Releases from Lake Powell can vary from Alternative A by up to 4 kaf in 3% of
36 months due to different ramp-down constraints. In years when HFEs would be implemented
37 under Alternative B, water may need to be reallocated from later months in the water year if the
38 targeted monthly volume was insufficient to allow for an HFE and meet minimum release
39 requirements.

40
41 Mean monthly volumes under Alternative B would be identical to those under
42 Alternative A and similar to current conditions. Volume would be highest during months with
43 relatively high hydropower demand (December, January, June, July, and August) when volume
44 would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly
45 volume would be approximately 570,000 to 1,200,000 ac-ft in other months.

TABLE 4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees Ferry to Diamond Creek

Season	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Winter (December–February)												
Alternative A	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative B	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative C	9.8	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.5	10.4	10.5	10.7
Alternative D	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative E	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.5	10.7
Alternative F	9.7	9.9	10.1	9.9	10.1	10.3	10.3	10.4	10.5	10.5	10.6	10.7
Alternative G	9.8	10.0	10.2	10.0	10.2	10.4	10.3	10.4	10.6	10.4	10.6	10.8
Spring (March–May)												
Alternative A	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.5	13.3	13.5	13.7
Alternative B	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.4	13.3	13.5	13.7
Alternative C	9.2	9.4	9.5	10.2	10.4	10.6	11.8	12.0	12.2	12.9	13.2	13.4
Alternative D	9.2	9.4	9.5	10.3	10.4	10.6	11.9	12.1	12.3	13.1	13.3	13.5
Alternative E	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.3	13.0	13.3	13.5
Alternative F	9.3	9.5	9.6	10.1	10.3	10.4	11.3	11.6	11.7	12.2	12.5	12.6
Alternative G	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.4	13.0	13.3	13.7
Summer (June–August)												
Alternative A	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	15.9	16.9	17.2	17.7
Alternative B	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	16.0	16.9	17.2	17.8
Alternative C	11.4	11.7	11.9	13.1	13.3	13.6	15.5	15.8	16.2	17.2	17.6	18.0
Alternative D	11.4	11.6	11.8	13.0	13.2	13.5	15.5	15.8	16.2	17.2	17.5	18.0
Alternative E	11.4	11.6	11.8	13.1	13.3	13.5	15.6	15.8	16.2	17.3	17.6	18.1

TABLE 4.2-2 (Cont.)

Season	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
<i>Summer (June–August) (Cont.)</i>												
Alternative F	11.6	11.9	12.1	13.5	13.7	14.0	16.2	16.6	17.0	18.2	18.6	19.2
Alternative G	11.3	11.6	11.8	13.0	13.3	13.6	15.6	15.9	16.4	17.4	17.8	18.3
<i>Fall (September–November)</i>												
Alternative A	12.2	12.4	12.6	13.1	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative B	12.2	12.4	12.6	13.0	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative C	12.0	12.3	12.6	13.1	13.2	13.5	14.6	14.8	15.0	15.6	15.9	16.1
Alternative D	12.1	12.4	12.6	13.0	13.2	13.4	14.3	14.5	14.7	15.2	15.5	15.6
Alternative E	12.1	12.4	12.6	13.0	13.2	13.5	14.4	14.6	14.8	15.3	15.5	15.7
Alternative F	12.0	12.3	12.6	13.1	13.3	13.5	14.6	14.8	15.0	15.7	16.0	16.1
Alternative G	12.2	12.4	12.7	13.0	13.2	13.5	14.3	14.4	14.6	15.1	15.3	15.5

1 Mean daily flows under Alternative B also would be similar to current conditions, and
2 highest in the higher volume months of December, January, June, July, and August, as well as
3 September when flows would range from approximately 11,200 to 24,600 cfs under the
4 scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to
5 14,400 cfs in other months.

6
7 Under Alternative B, the allowable daily change is higher than under Alternative A and
8 ranges from 6,000 to 12,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily
9 change would occur in December, January, July, and August, when mean daily change would
10 vary from about 2,500 to 12,000 cfs (Figure 4.2-4). In other months, mean daily change would
11 range from 3,000 to 10,000 cfs.

12
13 Modeled water temperature ranges and means under Alternative B are nearly identical to
14 those under Alternative A (Table 4.2-2) because the two alternatives have the same monthly
15 release volumes. Daily fluctuation differences, which are greater for Alternative B relative to
16 Alternative A, are thought to have a negligible impact on water temperature (Anderson and
17 Wright 2007). Other operational differences between the two alternatives related to ramp rates
18 and test flows (e.g., HFEs, hydropower improvement flows, and TMFs) would not affect
19 seasonal temperature trends.

20
21 Under Alternative B, there is a slightly lower probability of the occurrence of bacteria or
22 pathogen contamination along shorelines. This lower probability would result from the slightly
23 higher daily fluctuations under this alternative relative to Alternative A. Experimental
24 hydropower improvement flows would have the lowest probability of occurrence. The expected
25 probability of this contamination occurring is very low, and it would be localized and temporary.

26
27 In summary, compared to Alternative A, Alternative B would result in no change from
28 current condition related to lake elevations, annual operating tiers, monthly release volumes, or
29 mean daily flows, but would produce higher mean daily changes in flow. Hydropower
30 improvement flows would cause even greater mean daily flow changes. Compared to
31 Alternative A, there would be negligible differences in temperature or other water quality
32 indicators, but Alternative B has a slightly lower probability of the occurrence of bacteria or
33 pathogen contamination along shorelines.

34 35 36 **4.2.3.3 Alternative C**

37
38 Alternative C would show little or no difference from Alternative A with regard to
39 operating tier. The October through December release volume for Alternative C is 210 kaf less
40 than Alternative A in an 8.23-maf release year; this difference could result in a slightly higher
41 end-of-December elevation and sometimes a different operating tier. Alternative C would result
42 in a different operating tier from that under Alternative A in 2.1% of years.

43
44 The frequency of operating tiers under Alternative C would be very similar to that under
45 Alternative A. During the interim period (through 2026), Alternative C would operate at times
46 within each of the four operating tiers at the following mean annual frequencies: Upper Elevation

1 Balancing Tier—46.2%; Equalization Tier—38.1%; Mid-Elevation Release Tier—14.7%; and
2 Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative C has 1 year less
3 than Alternative A, with annual releases of 8.23 maf (average of 71.4% of years), and 1 year
4 more than Alternative A, with annual releases greater than 8.23 maf in an average of 28.6% of
5 years. Because of the lower October through December release volume, it is possible that the
6 higher elevation would result in Lake Powell operating in a higher operating tier. This is depicted
7 in Figure 4.2-8, which shows at least one trace that operates in the Upper Elevation Balancing
8 Tier instead of the Mid-Elevation Release Tier as compared to Alternative A (shown as a
9 decrease in the Mid-Elevation Release 75th percentile and a corresponding increase in the Upper
10 Elevation Balancing median relative to Alternative A).
11

12 During wet years, Lake Powell may not always be able to fully equalize within the water
13 year, resulting in annual releases extending beyond the water year. Under Alternative C, more
14 water would be released in the earlier months of the water year than under Alternative A;
15 therefore, it would not result in as many instances of annual releases extending beyond the water
16 year, nor volumes that are as high. Under Alternative C, the average number of occurrences of
17 annual releases extending beyond the water year per 20-year trace is less than under
18 Alternative A, with an average of 0.2 years per trace, and a range from zero to one occurrence
19 per 20-year period. The volume of annual releases extending beyond the water year also would
20 be less than under Alternative A, with an average volume of 107 kaf and a range from 0 to
21 1,210 kaf.
22

23 Under Alternative C, monthly release volumes in July through November would be lower
24 than under Alternative A. Release volumes from December through August are higher than those
25 under Alternative A. In years when HFEs would be implemented under Alternative C, water may
26 need to be reallocated from later months in the water year if the targeted monthly volume was
27 insufficient to allow for an HFE and meet minimum release requirements. In years when
28 experimental low summer flows would be implemented under Alternative C, the monthly
29 volumes in May and June would be increased to accommodate lower July through September
30 volumes. On the basis of release temperatures and the ability to achieve target downstream
31 temperatures, experimental low summer flows would be implemented on average 1.8 times per
32 20-year trace, with a range from zero to four per trace.
33

34 The inclusion of low summer flows under Alternative C would not affect operating tiers;
35 however, the volumes of annual releases extending beyond the water year would show some
36 slight differences, as do the end-of-year elevations at Lakes Powell and Mead. The median
37 difference in elevation when low summer flows would be implemented is 0.08 and 0.13 ft at
38 Lake Powell and Lake Mead, respectively.
39

40 Lake Powell end-of-December elevations under Alternative C would tend to be slightly
41 higher than those under Alternative A. Under Alternative C, the median elevation for Lake
42 Powell at the end of December was about 3,630 ft, and on average 1.5 ft higher than under
43 Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from
44 about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles, respectively. Under
45 Alternative C, end-of-December elevations at the 10th percentile were on average 0.7 ft higher
46 than those under Alternative A, and on average 1.0 ft higher than those at the 90th percentile

1 under Alternative A. Under Alternative C, the percentage of traces below minimum power pool
2 would be identical to those under Alternative A.

3
4 Lake Mead end-of-December elevations under Alternative C would tend to be slightly
5 lower than those under Alternative A. Under Alternative C, the median elevation for Lake Mead
6 at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near
7 the end of the period, and on average 0.6 ft lower than under Alternative A throughout the
8 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about
9 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about
10 1,010 ft to about 1,210 ft near the end of the period. Under Alternative C, elevations at the
11 10th percentile were on average 2.9 ft lower than Alternative A, with a maximum difference of
12 10 ft. Elevations at the 90th percentile were on average 3.2 ft lower than those under
13 Alternative A. Under Alternative C, the percentage of traces with Lower Basin Shortages are
14 sometimes 5% higher and sometimes 5% lower than under Alternative A; however, the general
15 trend and range of traces with shortages are similar to Alternative A, ranging from 0 for the first
16 2 years of the period, then increasing to 62% of traces near the end of the 20-year simulation.

17
18 Compared to Alternative A, mean monthly volume under Alternative C would be higher
19 (by 82,000 to 157,000 ac-ft) from February through May, and lower (by 111,000 to
20 200,000 ac-ft) in August through October; volume would be comparable to that under
21 Alternative A in other months (Figure 4.2-2). The pattern of monthly volumes results from
22 targeted lower volumes in August through October to conserve sand input from the Paria River
23 during the monsoon period. Volume in high-demand months would range from approximately
24 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from
25 approximately 490,000 to 1,100,000 ac-ft in other months.

26
27 Mean daily flows under Alternative C would follow the same pattern as monthly volume
28 and be higher (by 1,300 to 2,500 cfs) than Alternative A from February through May, and lower
29 (by 1,800 to 3,300 cfs) in August through October; mean daily flow would be comparable to that
30 under Alternative A in other months (Figure 4.2-3).

31
32 Under Alternative C, the allowable daily change is lower than under Alternative A, but is
33 proportional to monthly volume (Chapter 2). Mean daily change would be lower than under
34 Alternative A in all months and would range from 1,300 to 6,200 cfs (Figure 4.2-4).

35
36 Under Alternative C, mean winter temperatures are expected to warm the least, with a
37 difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations.
38 Summer temperatures are expected to warm the most as they move downstream, with an
39 approximately 5.8°C (11.7–17.6°C) difference. Spring temperatures would warm around 3.8°C
40 (9.4–13.2°C), and fall temperatures would warm about 3.6°C (12.3–15.9°C). The full range of
41 minimum and maximum values is presented in Table 4.2-2.

42
43 Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated
44 with Alternative C vary less than $\pm 0.4^\circ\text{C}$ from Alternative A depending on season. Thus, they are
45 not considered to be significantly different.

1 Under Alternative C, there is a slightly higher probability of the occurrence of bacteria or
2 pathogen contamination along shorelines. This higher probability would result from occasional
3 low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria
4 and pathogens compared to Alternative A. The expected probability of this contamination
5 occurring is very low and would be localized and temporary.
6

7 In summary, compared to Alternative A, Alternative C would result in some change from
8 current condition related to lake elevations, annual operating tiers, monthly release volumes, and
9 mean daily flows, but would result in lower mean daily changes in flow throughout the year.
10 Compared to Alternative A, there would greater summer warming and slightly increased
11 potential for bacteria and pathogens.
12

13 14 **4.2.3.4 Alternative D (Preferred Alternative)** 15

16 Alternative D would show little or no difference from Alternative A with regard to
17 operating tier. Alternative D does not result in different operating tiers than Alternative A in any
18 year, in any trace, because the October through December release volumes would be identical to
19 those under Alternative A.
20

21 During wet years, Lake Powell may not always be able to fully equalize within the water
22 year, resulting in annual releases extending beyond the water year. Under Alternative D, more
23 water would be released in the earlier months of the water year than under Alternative A;
24 therefore, it would not result in as many instances of annual releases extending beyond the water
25 year, nor volumes that are as high. Under Alternative D, the average number of occurrences of
26 annual releases extending beyond the water year per 20-year trace is less than under
27 Alternative A, with an average of 0.4 years per trace, and a range from zero to two occurrences
28 per 20-year period. The volume of annual release extending beyond the water year also would be
29 less than under Alternative A, with an average volume of 146 kaf and a range from 0 to
30 1,495 kaf.
31

32 In years without experimental low summer flows, the monthly release volumes under
33 Alternative D would be fairly constant throughout the year, the most constant of all alternatives
34 except Alternative G. In the years when HFEs would be implemented under Alternative D, water
35 may need to be reallocated from later months in the water year if the targeted monthly volume
36 was insufficient to allow for an HFE and meet minimum release requirements. In years when
37 experimental low summer flows would be implemented under Alternative D, the monthly
38 volumes in May and June would be increased to accommodate lower July through September
39 volumes. Under Alternative D, experimental low summer flows would be implemented only
40 during the second 10 years of the LTEMP period; on the basis of release temperatures and the
41 ability to achieve target downstream temperatures, these would take place on average 0.7 times
42 per 20-year trace, with a range of zero to three per trace.
43

44 Lake Powell end-of-December elevations under Alternative D would be nearly
45 indistinguishable from those under Alternative A. Under Alternative D, the median elevation for
46 Lake Powell at the end of December would be about 3,630 ft, on average 0.2 ft higher than under

1 Alternative A throughout the 20-year LTEMP period. Near the beginning of the period, end-of-
2 December elevations ranged from about 3,560 ft to about 3,660 ft at the 10th and
3 90th percentiles, respectively, and about 3,560 ft to about 3,680 ft near the end of the period.
4 Under Alternative D, end-of-December elevations were on average 0.2 ft and 0.1 ft higher than
5 those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative D, this
6 modeling showed 3 years out of 420 years (20 years and 21 traces) when Lake Powell would
7 drop temporarily below the 3,490-ft minimum power pool. This is one more year than under
8 Alternative A and is a result of Alternative D releasing 151 kaf more than Alternative A in the
9 October through March (the typical low elevation month) period in an 8.23-maf release year.

10
11 Lake Mead end-of-December elevations under Alternative D would be very similar to
12 those under Alternative A. Under Alternative D, the median elevation for Lake Mead at the end
13 of December was on average the same as Alternative A: about 1,100 ft near the beginning of the
14 period and about 1,080 ft near the end of the period. End-of-December elevations ranged from
15 about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles,
16 respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative C,
17 elevations were on average 0.7 ft and 0.4 ft lower than those under Alternative A at the 10th and
18 90th percentiles, respectively. Under Alternative D, implementation of low summer flows would
19 result in one additional trace in shortage in 2025 compared with Alternative A (1 year out of
20 420 years total). Otherwise, the general trend and range of traces with shortages are the same as
21 under Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62%
22 of traces near the end of the 20-year period.

23
24 Implementation of experimental low summer flows and sustained low flows for benthic
25 invertebrate production under Alternative D would not affect the operating tier, but slight
26 differences could result in annual releases extending beyond the water year and end-of-year
27 elevations at Lake Powell and Lake Mead.

28
29 Compared to Alternative A, mean monthly volume under Alternative D would be higher
30 (by 43,000 to 98,000 ac-ft) in October, November, February, March, and April, and lower (by
31 60,000 to 127,000 ac-ft) in December, January, July, August, and September; volume would be
32 comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly
33 volumes approximates that of Western Area Power Administration's (Western's) contract rate of
34 delivery. Volume in high-demand months would range from approximately 640,000 to
35 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 620,000
36 to 1,200,000 ac-ft in other months. Note that adjustments to Alternative D made after modeling
37 was completed resulted in a 50-kaf increase in August (changed from 750 to 800 kaf) and a
38 corresponding 25-kaf decrease in May and June (changed from 657 to 632 kaf and 688 to 663
39 kaf, respectively) in an 8.23-maf year.

40
41 Mean daily flows under Alternative D would follow the same pattern as monthly volume
42 and be higher (by 700 to 3,000 cfs) than Alternative A in October, November, February, March,
43 and April, and lower (by 1,000 to 2,100 cfs) in December, January, July, August, and September;
44 volume would be comparable to that under Alternative A in May and June (Figure 4.2-3).

1 Under Alternative D, the allowable daily change would be proportional to monthly
2 volume (Section 2.2.4). Mean daily change would be slightly higher than that under
3 Alternative A in October through June, but the same or less in July through August. Mean daily
4 change would range from about 2,700 to 7,600 cfs (Figure 4.2-4).
5

6 Under Alternative D, mean winter temperatures are expected to warm the least, with a
7 difference of about 0.6°C (10.0–10.6°C) between the Lees Ferry and Diamond Creek locations.
8 Summer temperatures are expected to warm the most as they move downstream, with an
9 approximately 6.0°C (11.6–17.5°C) difference. Spring temperatures would warm around 3.9°C
10 (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of
11 minimum and maximum values is presented in Table 4.2-2.
12

13 Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated
14 with Alternative D vary less than $\pm 0.3^\circ\text{C}$ from Alternative A depending on season. Thus, they
15 are not considered to be significantly different.
16

17 Under Alternative D, there is a slightly higher probability of the occurrence of bacteria or
18 pathogen contamination along shorelines. This higher probability would result from occasional
19 low summer flows and relatively frequent HFES, which could increase the occurrence of bacteria
20 and pathogens compared to Alternative A. The expected probability of this contamination
21 occurring is very low, and it would be localized and temporary.
22

23 In summary, compared to Alternative A, Alternative D would result in negligible changes
24 from current conditions related to lake elevations, no change in annual operating tiers, more even
25 monthly release volumes and mean daily flows, and lower mean daily changes in flow.
26 Compared to Alternative A, there would be greater summer warming and slightly increased
27 potential for bacteria and pathogens.
28
29

30 **4.2.3.5 Alternative E**

31

32 Alternative E would show little or no difference from Alternative A with regard to
33 operating tier. Alternative E does not result in different operating tiers than Alternative A in any
34 year, in any trace, because the October through December release volumes would be identical to
35 those under Alternative A.
36

37 During wet years, Lake Powell may not always be able to fully equalize within the water
38 year, resulting in annual releases extending beyond the water year. Under Alternative E, more
39 water would be released in the earlier months of water year than under Alternative A; therefore,
40 it would not result in as many instances of annual releases extending beyond the water year, nor
41 volumes that are as high. Under Alternative E, the average number of occurrences of annual
42 releases extending beyond the water year per 20-year trace is less than Alternative A with an
43 average of 0.2 years per trace, and a range from zero to one occurrence per 20-year period. The
44 volume of annual release extending beyond the water year also would be less than under
45 Alternative A, with an average volume of 109 kaf and a range from 0 to 1,022 kaf.
46

1 In years without experimental low summer flows, the monthly releases volumes under
2 Alternative E would be fairly constant throughout the year and comparable to Alternative D. In
3 years when HFEs would be implemented under Alternative E, water may need to be reallocated
4 from later months in the water year if the targeted monthly volume was insufficient to allow for
5 an HFE and meet minimum release requirements. In years when experimental low summer flows
6 would be implemented under Alternative E, the monthly volumes in May and June would be
7 increased to accommodate lower July through September volumes. On the basis of release
8 temperatures and the ability to achieve target downstream temperatures, experimental low
9 summer flows would be implemented on average 1.5 times per 20-year trace, with a range from
10 zero to four per trace.

11
12 Lake Powell end-of-December elevations under Alternative E would be very similar to
13 those under Alternative A. Under Alternative E, the median elevation for Lake Powell at the end
14 of December was about 3,630 ft, and on average 0.3 ft higher than under Alternative A
15 throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the
16 period ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively,
17 and from about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative E, end-of-
18 December elevations were on average 0.2 ft and 0.3 ft higher than those at the 10th and 90th,
19 respectively, under Alternative A. For Alternative E, this modeling showed 3 years out of
20 420 years (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490 ft
21 minimum power pool. This is one more year than under Alternative A. This is a result of
22 Alternative E releasing 203 kaf more than Alternative A in the October through March (the
23 typical low elevation month) period in an 8.23-maf release year.

24
25 Lake Mead end-of-December elevations under Alternative E would be very similar to
26 those under Alternative A. Under Alternative E, the median elevation for Lake Mead at the end
27 of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of
28 the period, and on average 0.1 ft lower than under Alternative A throughout the 20-year LTEMP
29 period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the
30 beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about
31 1,210 ft near the end of the period. Under Alternative E, throughout the period elevations
32 averaged 0.9 ft and 0.7 ft lower than those under Alternative A at the 10th and 90th percentiles,
33 respectively. Under Alternative E, implementation of low summer flows would result in one
34 additional trace in shortage in 2020 compared with Alternative A (1 year out of 420 years total)
35 and one fewer trace in 2022. Otherwise, the general trend and range of traces with shortages are
36 the same as under Alternative A, ranging from zero for the first 2 years of the model period, then
37 increasing to 62% of traces near the end of the 20-year period.

38
39 Implementation of experimental low summer flows and sustained low flows for benthic
40 invertebrate production under Alternative E would not affect the operating tier, but slight
41 differences could result for volumes of annual release extending beyond the water year and end-
42 of-year elevations at Lake Powell and Lake Mead.

43
44 Compared to Alternative A, mean monthly volume under Alternative E would be higher
45 (by 45,000 to 128,000) in October, November, February, March, and April, and lower (by
46 30,000 to 242,000 ac-ft) in December, January, July, August, and September; volume would be

1 comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly
2 volumes follows that of Western's contract rate of delivery, but it is lower in August and
3 September to target lower volumes in August through October to conserve sand input from the
4 Paria River during the monsoon period. Volume in high-demand months would range from
5 approximately 660,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range
6 from approximately 580,000 to 1,100,000 ac-ft in other months.
7

8 Mean daily flows under Alternative E would follow the same pattern as monthly volume
9 and would be higher (by 700 to 2,100 cfs) than Alternative A in October, November, February,
10 March, and April, and lower in (by 500 to 4,000 cfs) December, January, July, August, and
11 September; volumes would be comparable to those under Alternative A in May and June
12 (Figure 4.2-3).
13

14 Under Alternative E, the allowable daily change would be proportional to monthly
15 volume (Chapter 2), and higher than under Alternative A, in all months but September and
16 October (lower in these two months). Mean daily change would range from 1,100 to 9,600 cfs
17 (Figure 4.2-4).
18

19 Under Alternative E, mean winter temperatures are expected to warm the least, with a
20 difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations.
21 Summer temperatures are expected to warm the most as they move downstream, with an
22 approximately 6.0°C (11.6–17.6°C) difference. Spring temperatures would warm around 3.9°C
23 (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of
24 minimum and maximum values is presented in Table 4.2-2.
25

26 Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated
27 with Alternative E vary less than $\pm 0.4^\circ\text{C}$ from Alternative A depending on season. Thus, they are
28 not considered to be significantly different.
29

30 Under Alternative E, there is a slightly higher probability of the occurrence of bacteria or
31 pathogen contamination along shorelines. This higher probability would result from occasional
32 low summer flows and relatively frequent HFES, which could increase the occurrence of bacteria
33 and pathogens compared to Alternative A. The expected probability of this contamination
34 occurring is very low, and it would be localized and temporary.
35

36 In summary, compared to Alternative A, Alternative E would result in negligible change
37 from current condition related to lake elevations, no change in annual operating tiers, more even
38 monthly release volumes and mean daily flows, and higher mean daily changes in flow.
39 Compared to Alternative A, there would be greater summer warming and slightly increased
40 potential for bacteria and pathogens.
41

42 43 **4.2.3.6 Alternative F** 44

45 Alternative F would show the greatest differences from Alternative A of all the
46 alternatives with regard to operating tier. The October-through-December release volume for

1 Alternative F is 534 kaf less than Alternative A in an 8.23-maf year; this difference could result
2 in a slightly higher end-of-December Lake Powell elevation, and sometimes a different operating
3 tier. Alternative F would result in a different operating tier from that under Alternative A in 2.1%
4 of years.

5
6 Alternative F would result in fewer instances of the Mid-Elevation Release Tier (decrease
7 of 2.2% of years on average) and more instances of the Upper Elevation Balancing and
8 Equalization Tiers (increase of 1.1% of years on average for both tiers). During the interim
9 period (through 2026), Alternative F would operate at times within each of the four operating
10 tiers at the following mean annual frequencies: Upper Elevation Balancing Tier—47.3%;
11 Equalization Tier—38.5%; Mid-Elevation Release Tier—13.2%; and Lower Elevation Balancing
12 Tier—1.1%. After the interim period, Alternative F has annual releases of 8.23 maf in an average
13 of 72.1% of years and annual releases greater than 8.23 maf in an average of 27.9% of years.
14

15 During wet years, Lake Powell may not always be able to fully equalize within the water
16 year, resulting in annual releases extending beyond the water year. Under Alternative F, more
17 water would be released in the earlier months of the water year than under Alternative A;
18 therefore, it would not result in as many instances of annual releases extending beyond the water
19 year, nor volumes that are as high. Under Alternative F, the average number of occurrences of
20 annual releases extending beyond the water year per 20-year trace is less than under
21 Alternative A, and the lowest of all the alternatives with an average of 0.1 years per trace, and a
22 range from zero to one occurrence per 20-year period. The volume of annual release extending
23 beyond the water year is also less than under Alternative A, and the lowest of all alternatives
24 with an average volume of 69 kaf and a range of 0 to 1,135 kaf.
25

26 Under Alternative F, monthly release volumes follow a more natural hydrograph pattern
27 than other alternatives, with the highest flows in the spring months April through June and lower
28 flows in the remaining months. Release volumes in December through August are significantly
29 lower than those under Alternative A. When HFEs would be implemented under Alternative F,
30 water would be reallocated from later months in the water year if the targeted monthly volume
31 was insufficient to allow for an HFE and meet minimum release requirements.
32

33 Lake Powell end-of-December elevations under Alternative F would be higher than those
34 under Alternative A; this would be the largest difference of all the alternatives. Under
35 Alternative F, the median elevation for Lake Powell at the end of December was about 3,630 ft,
36 on average 3.2 ft higher than under Alternative A throughout the 20-year LTEMP period. End-
37 of-December elevations near the beginning of the period ranged from about 3,565 ft to about
38 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,565 ft to about 3,680 ft
39 near the end of the period. Under Alternative E, end-of-December elevations were on average
40 5.1 ft and 1.8 ft higher than those at the 10th and 90th percentiles, respectively, under
41 Alternative A. For Alternative F, this modeling showed there would be no occurrences of
42 Lake Powell elevations dropping below the minimum power pool.
43

44 Lake Mead end-of-December elevations under Alternative F would be lower than those
45 under Alternative A. Under Alternative F, the median elevation for Lake Mead at the end of
46 December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the

1 period, and on average 2.9 ft lower than under Alternative A throughout the 20-year LTEMP
2 period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the
3 beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about
4 1,210 ft near the end of the period. Under Alternative F, elevations throughout the period were
5 on average 4.0 ft and 2.3 ft lower than those under Alternative A at the 10th and 90th percentiles,
6 respectively. Near the end of the period, however, elevations under Alternative F were up to
7 12.5 ft lower than those under Alternative A at the 10th percentile. Under Alternative F, the
8 percentage of traces with Lower Basin Shortages would be higher than that under Alternative A
9 in nearly all years, with differences ranging from 0 to 10% higher than under Alternative A.
10 However, the general trend and range of traces with shortages are the same as under
11 Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62% of
12 traces near the end of the 20-year period.

13
14 Compared to Alternative A, mean monthly volume under Alternative F would be much
15 higher (by 439,000 to 651,000 ac-ft) in April, May, and June, but much lower (by 214,000 to
16 433,00 ac-ft) in December, January, July, August, and September (Figure 4.2-2). This monthly
17 pattern is intended to more closely match a natural hydrograph with high spring flows and low
18 summer through winter flows. Volume in high-demand months would range from approximately
19 430,000 to 1,700,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from
20 approximately 440,000 to 1,500,000 ac-ft in other months.

21
22 Mean daily flows under Alternative F would follow the same pattern as monthly volume
23 and would be much higher (by 7,400 to 10,600 cfs) in April, May, and June, but much lower (by
24 3,600 to 7,000 cfs) in December, January, July, August, and September (Figure 4.2-3).

25
26 Under Alternative F, flow typically would not change within days except to ramp up and
27 down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

28
29 Under Alternative F, mean winter temperatures (Table 4.2-2) are expected to warm the
30 least, with a difference of about 0.6°C (9.9–10.6°C) between Lees Ferry and Diamond Creek.
31 Summer temperatures are expected to warm the most as they move downstream, with an
32 approximately 6.8°C (11.9–18.6°C) difference. Spring temperatures would warm around 3.0°C
33 (9.5–12.5°C), and fall temperatures would warm about 3.7°C (12.3–16.0°C). The full range of
34 minimum and maximum values is presented in Table 4.2-2.

35
36 Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated
37 with Alternative F are different than those under Alternative A in the spring and summer
38 seasons. In the spring, the downstream temperature difference at Diamond Creek would be
39 approximately 1.1°C cooler than that for Alternative A. This is likely due to the fact that this
40 alternative has much higher average spring releases, so larger volumes of seasonally cooler
41 Lake Powell water are released downstream (Vernieu et al. 2005; Reclamation 2011b) than in
42 any of the other LTEMP alternatives. In addition, Alternative F features a total of 22 high flows
43 (both sediment-triggered HFEs and other high flow events) in the spring, which may add to the
44 overall downstream cooling effect.

45

1 For the summer period, the downstream mean temperature at Diamond Creek would be
2 approximately 1.4°C warmer than that under Alternative A. This warming is a result of much
3 lower summer flows associated with Alternative F compared to all of the other LTEMP
4 alternatives. These lower flows allow for a larger surface-area-to-volume ratio and greater
5 exposure time with the warmer summer ambient air, which facilitates downstream warming
6 (Vernieu et al. 2005).
7

8 Under Alternative F, there is a slightly higher probability of the occurrence of bacteria or
9 pathogen contamination along shorelines. This higher probability would result from annual low
10 steady flows and relatively frequent HFES, which could increase the occurrence of bacteria and
11 pathogens compared to Alternatives A, B, C, D, and E but is still considered very low, and it
12 would be localized and temporary.
13

14 In summary, compared to Alternative A, Alternative F would result in some change from
15 current conditions related to lake elevations and annual operating tiers, large changes in monthly
16 release volumes and mean daily flows, and steady flows throughout the year. Compared to
17 Alternative A and the other alternatives, there would be greater summer warming and slightly
18 increased potential for bacteria and pathogens.
19
20

21 **4.2.3.7 Alternative G**

22

23 Alternative G is expected to show little or no difference from Alternative A with regard
24 to operating tier. The October through December release volume for Alternative G is 75 kaf
25 more than Alternative A in an 8.23-maf year; this difference could result in a slightly lower end-
26 of-December Lake Powell elevation and sometimes a different operating tier. Alternative G
27 would result in a different operating tier from that under Alternative A in 0.7% of years.
28

29 The frequency of operating tiers under Alternative G would be identical to that under
30 Alternative A during the interim period (through 2026) and nearly the same as Alternative A
31 after the interim period. After the interim period, Alternative G would have at least one trace
32 with fewer annual releases of 8.23 maf (average of 71.4% of years) than Alternative A and at
33 least one trace with more annual releases greater than 8.23 maf (average of 28.6% of years) than
34 Alternative A.
35

36 During wet years, Lake Powell may not always be able to fully equalize within the water
37 year, resulting in annual releases extending beyond the water year. Under Alternative G, more
38 water would be released than under Alternative A in the earlier months of the water year;
39 therefore, Alternative G would not result in as many instances of annual releases extending
40 beyond the water year, nor volumes that are as high. Under Alternative G, the average number of
41 occurrences of annual releases extending beyond the water year per 20-year trace is less than
42 under Alternative A with an average of 0.5 years per trace, and a range from zero to two
43 occurrences per 20-year period. The volume of annual release extending beyond the water year
44 also would be less than under Alternative A, with an average volume of 151 kaf and a range
45 from 0 to 1,440 kaf.
46

1 Under Alternative G, monthly release volumes are as constant as possible, given
2 hydrologic uncertainty throughout the water year. Release volumes during December through
3 August are slightly higher than those under Alternative A. In years when HFEs would be
4 implemented under Alternative G, water may need to be reallocated from later months in the
5 water year if the targeted monthly volume was insufficient to allow for an HFE and meet
6 minimum release requirements.
7

8 Lake Powell end-of-December elevations under Alternative G would tend to be slightly
9 lower than those under Alternative A. Under Alternative G, the median elevation for
10 Lake Powell at the end of December would be nearly the same as under Alternative A (about
11 3,630 ft), and on average 0.4 ft lower than under Alternative A throughout the 20-year LTEMP
12 period. End-of-December elevations near the beginning of the period ranged from about 3,560 ft
13 to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,560 ft to about
14 3,680 ft near the end of the period. Under Alternative G, end-of-December elevations were on
15 average 1.2 ft and 0.3 ft lower than those at the 10th and 90th percentiles, respectively, under
16 Alternative A. Under Alternative G, there are two occurrences of Lake Powell below the
17 minimum power pool, the same as under Alternative A.
18

19 Lake Mead end-of-December elevations for Alternative G would tend to be slightly
20 higher than those under Alternative A. Under Alternative G, the median elevation for Lake Mead
21 at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near
22 the end of the period, and on average 1.4 ft higher than under Alternative A throughout the
23 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about
24 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about
25 1,010 ft to about 1,210 ft near the end of the period. Under Alternative G, elevations at the 10th
26 percentile were sometimes higher and sometimes lower compared to Alternative A, with
27 differences ranging from 6.8 ft lower to 4.0 ft higher throughout the 20-year period. Elevations at
28 the 90th percentile were nearly identical to those under Alternative A (the maximum difference
29 in any year was 1.0 ft). Under Alternative G, there was one fewer trace in shortage in 2020
30 compared to Alternative A (1 year out of 420 years total) and one more trace in 2020. Otherwise,
31 the general trend and range of traces with shortage are the same as under Alternative A, ranging
32 from zero for the first 2 years of the model run, then increasing to 62% of traces near the end of
33 the 20-year period.
34

35 Compared to Alternative A, mean monthly volume under Alternative G would be higher
36 (by 71,000 to 286,000 ac-ft) in October, November, March, and April, but lower (by 139,000 to
37 196,000 ac-ft) in December, January, July, and August (Figure 4.2-2). The monthly pattern for
38 Alternative G is approximately equal to monthly volumes throughout the year, except for
39 adjustments due to changes in forecast. Volume in high-demand months would range from
40 approximately 60,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range
41 from approximately 600,000 to 1,300,000 ac-ft in other months.
42

43 Mean daily flows under Alternative G would follow the same pattern as monthly volume
44 and would be higher (by 1,200 cfs to 4,800 cfs) in October, November, March, and April, but
45 lower (by 2,300 to 3,200 cfs) in December, January, July, and August (Figure 4.2-3).
46

1 Under Alternative G, flow typically would not change within days except to ramp up and
2 down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

3
4 Under Alternative G, mean winter temperatures are expected to warm the least, with a
5 difference of about 0.6°C (10.0–10.6°C) between Lees Ferry and Diamond Creek. Summer
6 temperatures are expected to warm the most as they move downstream, with an approximately
7 6.2°C (11.6–17.8°C) difference. Spring temperatures would warm around 3.9°C (9.4–13.3°C),
8 and fall temperatures would warm about 2.9°C (12.4–15.3°C). The full range of minimum and
9 maximum values is presented in Table 4.2-2.

10
11 Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated
12 with Alternative G are slightly warmer than those under Alternative A in the summer season
13 (temperature difference at Diamond Creek is approximately 0.6°C warmer than that under
14 Alternative A). As under Alternative F, this summer warming is likely a result of the lower
15 summer flows compared to those of Alternative A, which would facilitate downstream warming
16 (Vernieu et al. 2005). The degree of warming is less than that observed under Alternative F,
17 because summer flows associated with Alternative G are somewhat higher in comparison.

18
19 Under Alternative G, there is a slightly higher probability of the occurrence of bacteria or
20 pathogen contamination along shorelines. This higher probability would result from year-round
21 steady flows and relatively frequent HFEs, which could increase the occurrence of bacteria and
22 pathogens compared to Alternatives A, B, C, D, and E, but is still considered very low, and it
23 would be localized and temporary.

24
25 In summary, compared to Alternative A, Alternative G would result in negligible change
26 from current conditions related to lake elevations and annual operating tiers, even monthly
27 release volumes and mean daily flows, and steady flows throughout the year. Compared to
28 Alternative A, there would be greater summer warming and slightly increased potential for
29 bacteria and pathogens.

30 31 32 **4.3 SEDIMENT RESOURCES**

33
34 This section presents an analysis of
35 impacts on sediment resources of the Colorado
36 River corridor between Glen Canyon Dam and
37 Lake Mead, and inflow deltas in Lake Mead.
38 Sediment resources include sandbars, beaches,
39 and lake deltas. Sediment is one of the
40 fundamental components of the ecosystem along
41 the river corridor in Glen and Grand Canyons.
42 The dynamics considered are the building and
43 erosion of sandbars and beaches as well as the
44 sediment remaining in the river channel, in the
45 river corridor below the dam. The sediment

Issue: How do alternatives affect sediment resources in the project area?

Impact Indicators:

- The amount of sand transported during high flows relative to total sand transport
- Sand mass balance in Marble Canyon
- The size and position of the Colorado River delta in Lake Mead

1 objective, as stated in Section 1.4, is to “increase and retain fine sediment volume, area, and
2 distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average
3 base flow for ecological, cultural, and recreational purposes.” This section evaluates alternatives
4 against this objective.
5

6 Quantitative analysis using a set of numerical models was conducted for the Colorado
7 River from Lees Ferry (RM 0) to Phantom Ranch (RM 87). Because a quantitative model is only
8 available from Lees Ferry to RM 87, impact assessments for the Colorado River corridor
9 upstream of Lees Ferry, downstream of RM 87, and for lake deltas are more qualitative in nature
10 but were considered sufficient to assess these impacts.
11

12 There are two generally opposing processes related to sediment resources downstream of
13 Glen Canyon Dam: (1) sediment deposition in sandbars at elevations above the range of normal
14 flows and (2) retention of sediment within a reach of the river. Because of the limited sand
15 supply, the flows needed to achieve the first objective (e.g., building high-elevation sandbars)
16 reduce the amount of sand retained on the riverbed within a reach. Using dam operations, it is
17 not possible to build high-elevation sandbars without transporting sand out of the reach.
18

19 Operations at Glen Canyon Dam directly affect sediment resources via changes in
20 releases and corresponding downstream flows and changes in reservoir elevation in Lakes
21 Powell and Mead. These changes can occur on hourly, daily, monthly, and annual timescales.
22 Changes in river flow result in changes in sandbar sediment storage and riverbed sand storage.
23 Aspects of operations and river flow that affect sediment resources are related to the monthly
24 distribution of annual release volumes, daily fluctuations, and the frequency, magnitude, and
25 duration of HFEs, TMFs, and proactive spring HFEs. This section analyzes the impacts of
26 LTEMP alternatives on these resources for the 20-year LTEMP period.
27
28

29 **4.3.1 Analysis Methods**

30
31 Sediment resources, such as sandbars and riverbed sand, are linked to flow and to each
32 other, just as most other resources discussed in this DEIS are linked to sediment.
33

34 Impacts were analyzed on the basis of the following categories of information, which are
35 further explained below:
36

- 37 • Records of river stage, streamflow, and sediment discharge at USGS gaging
38 stations along the river and on principal sediment-producing tributaries;
39
- 40 • Sandbar measurements made by Northern Arizona University;
41
- 42 • Published journal articles; and
43
- 44 • Results from the modified Sand Budget Model.
45

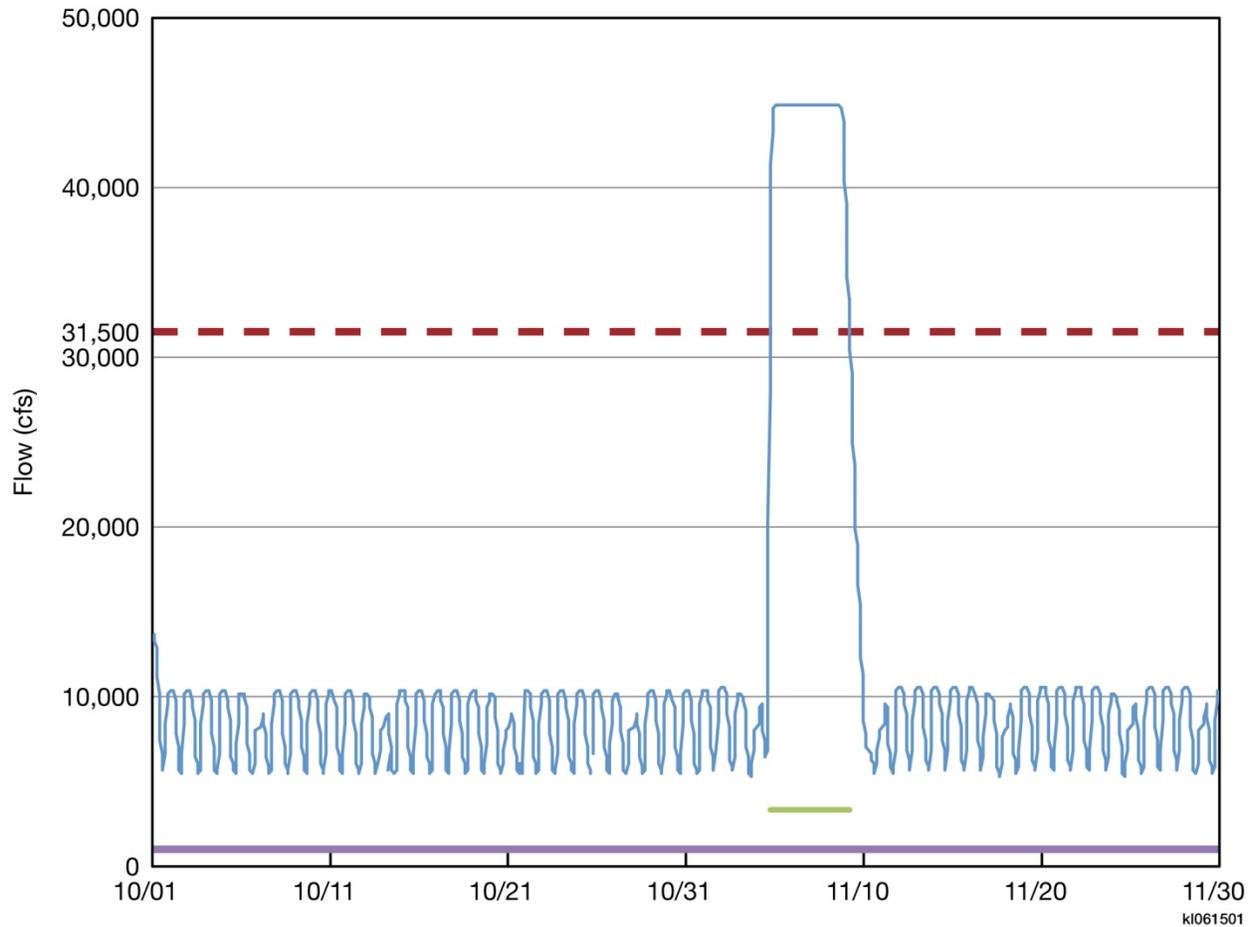
1 Sandbar deposits (and sandbar-dependent resources such as camping beaches and some
2 archaeological sites) are affected by the amount of riverbed sand transported under a given
3 alternative. A long-term net loss of riverbed sand would result in long-term loss in the number
4 and size of sandbars, with corresponding changes in aquatic and riparian habitat
5 (Reclamation 1995). Changes in sandbar and riverbed sand depend primarily on tributary sand
6 supply; the magnitude, frequency, and duration of HFEs; and the magnitude of daily powerplant
7 fluctuations.

8
9 Currently, there is no available model that can predict sandbar response to differing flow
10 release volumes and patterns. It has been established, however, that “large eddy sandbars form
11 when suspended-sediment loads are transported in high concentrations by the main flow. High
12 sandbars are constructed by large magnitude floods that rise to relatively high elevations”
13 (Schmidt and Grams 2011a). Thus, having high flows that are rich in suspended sediment
14 provide the means for potential sandbar growth.

15
16 Because a model is not available to simulate reach-wide sandbar response to dam
17 operations, an indicator of sandbar building was developed that represents the conditions
18 necessary for sandbar deposition (high flows rich in suspended sediment). The potential for
19 building sandbars was estimated using the Sand Load Index, which is a comparison of the mass
20 of sand transported at river flows $\geq 31,500$ cfs relative to the total mass of sand transported at all
21 flows (Figure 4.3-1). The index varies from 0 (no sand transported at flows $\geq 31,500$ cfs) to 1 (all
22 sand transported at flows $\geq 31,500$ cfs); the larger the Sand Load Index for an alternative, the
23 more potential there is for bar growth (Appendix E). The Sand Load Index only estimates the
24 potential for (and not actual) bar growth, because all sandbars have a maximum potential
25 deposition volume; the closer any given bar is to full, the less deposition will occur (Wiele and
26 Torizzo 2005). The Sand Load Index does not address fully the erosion of sandbars from
27 intervening flows between HFEs.

28
29 The increase in potential sandbar growth necessarily increases the mass of sand that
30 moves downstream, decreasing the sand budget. That is, having a high potential for bar growth
31 (resulting from a high Sand Load Index) causes a decrease in the amount of sand on the riverbed,
32 and having a low potential for bar growth (resulting from a low Sand Load Index) allows for
33 more sand to be retained on the riverbed. The measure of sand budget used in this analysis is the
34 Sand Mass Balance Index (Figure 4.3-2) calculated for Marble Canyon (RM 0 to RM 61); it is
35 the estimated mass of sand remaining at the end of the 20-year LTEMP period relative to the
36 sand mass at the start of the period. Data used to calculate the Sand Mass Balance Index and the
37 Sand Load Index come from Sand Budget Model outputs.

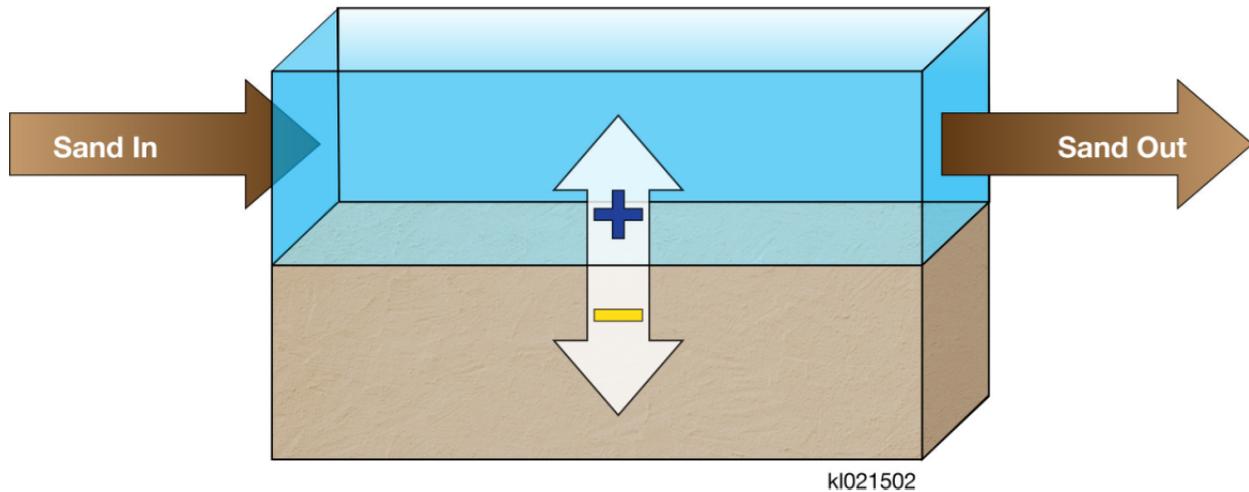
38
39 The Sand Budget Model (Wright et al. 2010; Russell and Huang 2010) is a numerical
40 model that tracks sand storage and transport from Lees Ferry (RM 0) to Phantom Ranch
41 (RM 87). The Sand Budget Model was modified for the purpose of analyzing the impacts of
42 LTEMP alternatives on the sand budget in Marble Canyon (Appendix E). The Sand Budget
43 Model uses empirically based rating curves to compute the sand budget in three reaches; RM 0 to
44 RM 30, RM 30 to RM 61, and RM 61 to RM 87. Modifications to the Sand Budget Model that
45 were implemented for the purposes of the analysis in this DEIS include (1) determining when
46 HFEs would be triggered, (2) reallocation of monthly water volumes (less water released in



1
 2 **FIGURE 4.3-1 Conceptual Depiction of the Sand Load Index (The blue line is the time series of**
 3 **river flow, and the dashed red line is the threshold condition of 31,500 cfs. The green lines**
 4 **represent the amount of time during which river flow is $\geq 31,500$ cfs. The purple line represents the**
 5 **entire time period of interest. The Sand Load Index is the amount of sand that is transported**
 6 **during the time represented by the green line, relative to the amount of sand transported during**
 7 **the time represented by the purple line.)**
 8
 9

10 months without HFEs to accommodate HFE water release volume in months with HFEs), and
 11 (3) implementation of a trout recruitment model provided by fish subject matter experts to
 12 identify years when TMFs would be triggered (Section 4.5).
 13

14 Potential future sediment delivery from the Paria River can affect results from the
 15 modified Sand Budget Model. The mean and median annual sand load from the Paria River for
 16 the approximately 50-year time period from October 1, 1963, to January 1, 2014, is
 17 approximately 761,000 metric tons and 756,000 metric tons, respectively (Topping 2014;
 18 GCMRC 2015b). Three different time series of sediment load for the Paria River were
 19 considered to account for uncertainty (Appendix E), with the mean annual input ranging from
 20 648,000 metric tons to 918,000 metric tons. The three 20-year time series selected approximate
 21 the 10, 50, and 90% exceedance probabilities, as well as represent the entire historical sediment
 22 record explicitly.



1
2 **FIGURE 4.3-2 Conceptual Depiction of the Sand Mass Balance Model (The large rectangular solid**
3 **is a control volume [lower half sand bed and upper half water]. Water and sand are flowing in from**
4 **the left and out to the right. Purple plus symbol represents the case of a positive Sand Mass Balance**
5 **where there is an increase in sand thickness due to the Sand In value being greater than the Sand**
6 **Out value for a given time period. The yellow minus sign represents the case of a negative Sand**
7 **Mass Balance, where there is a decrease in sand thickness due to the Sand Out value being greater**
8 **than the Sand In value for a given time period.)**
9

10
11 Each alternative was modeled in the modified Sand Budget Model with 21 different
12 potential hydrology scenarios (Section 4.1) and three different potential Paria River sediment
13 loads (Section 4.3.1, Appendix E) to account for uncertainty in future conditions. Comparisons
14 between alternatives are made using the average of these 63 combinations of simulations per
15 alternative, and confidence in the comparisons can be made by considering the inter-quartile
16 range of the 63 simulations. The inter-quartile range indicates that 50% of the estimated values
17 fall within this range, 25% of the values are below this range, and 25% are above this range.
18

19 The output of the Sand Budget Model includes the hourly time series of both the mass of
20 sand transported at the downstream boundary of each reach and the sand budget (Sand In minus
21 Sand Out) for each of the three reaches (Figure 4.3-2). Both of these time series are used in the
22 assessment of impacts on sediment resources.
23

24 Impacts on sediment resources in the Grand Canyon upstream of RM 87, as analyzed
25 here, are considered in general to be indicative of impacts further downstream, although the
26 timing and magnitude of effects may be different. A quantitative assessment of the alternatives
27 on the sediment resource downstream of RM 87 has not been made, but the literature suggests
28 that the relative rankings of the alternatives would be maintained for downstream reaches
29 (Hazel et al. 2010; Grams et al. 2015).
30

31 Lake deltas can be described by their size, which is directly affected by the amount of
32 sand delivered to the delta, and by longitudinal position in a canyon, which is directly affected by
33 lake elevation.

1 The position of the Lake Powell deltas, which occur at the inflows of both the mainstem
2 Colorado River and its tributaries, is dictated by the water surface elevation of Lake Powell.

3
4 The size of any given delta on Lake Powell, whether it is the mainstem Colorado River or
5 the tributaries, will not be affected by Glen Canyon Dam operations because operations cannot
6 affect the amount of sediment being delivered to the upstream deltas.

7
8 The positions of the Lake Mead deltas, which occur at the inflows of both the mainstem
9 Colorado River and its tributaries, are dictated by the elevation of Lake Mead. Lake Mead
10 elevations are analyzed on a monthly timescale, and the change in elevation from one month to
11 the next depends primarily on the amount of water released from Glen Canyon Dam during that
12 month and the release schedule from Hoover Dam. A lower release volume from Hoover Dam
13 and a higher release volume from Glen Canyon Dam would result in a higher water surface
14 elevation in Lake Mead, causing deltas to form farther up the canyon. The size of Lake Mead's
15 tributary deltas would not be affected by Glen Canyon Dam operations because these operations
16 cannot affect the amount of sediment being delivered to the lake's tributary deltas. Glen Canyon
17 dam operations can only affect the amount of sediment being delivered to the Colorado River
18 delta in Lake Mead. The sand mass balance results from the modified Sand Budget Model are
19 used to estimate the relative effects of the alternatives on the amounts of sediment that eventually
20 would reach the Colorado River delta in Lake Mead under the alternatives.

21 22 23 **4.3.2 Summary of Impacts**

24
25 General impacts on sandbars, riverbed sand, and lake deltas are discussed below. Specific
26 impacts on these resources are discussed under each alternative in Section 4.3.3. These impacts
27 vary among the alternatives as a result of differences in dam operations, including monthly
28 distribution of annual release volume, within-day fluctuations in releases, and the frequency,
29 magnitude, and duration of high flows, such as sediment-triggered HFEs, TMFs, and proactive
30 spring HFEs. Of these three types of high flows, sediment-triggered HFEs result in the largest
31 impact on sediment resources.

32
33 Sandbars are built by high flows. According to Schmidt and Grams (2011a), "the HFE
34 research program demonstrated that eddy sandbars are quickly constructed by high flows if those
35 flows have high suspended-sand concentrations." They also state that "high flows similar in
36 magnitude to those that occurred during the HFEs of 1996, 2004, and 2008 effectively mobilize
37 accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild
38 eddy sandbars in Marble and Grand Canyons" (Schmidt and Grams 2011a). This physical
39 understanding of the process was verified in subsequent high flows experiments. In discussing
40 the three high flows since the new HFE protocol (2012, 2013, and 2014), Grams et al. (2015)
41 note that "time-lapse images showed that at least half the monitored sandbars increased in size
42 following each controlled flood," and that resource managers "consider the 2012–2014 results
43 encouraging." Sandbars cannot get bigger without high flows.

44
45 Sandbars erode between large flow events. Erosion rates tend to be highest immediately
46 after a flood (when bars have the most sediment available for erosion), then decrease with time

1 (Grams et al. 2010). Furthermore, “monitoring data show that sandbars erode more quickly as
2 release volumes and daily fluctuations increase, whereas the rate of erosion is reduced when
3 tributary sand inputs continue to occur following sandbar building” (Melis et al. 2011). Steadier
4 flows erode bars at a lower rate than fluctuating flows (Wright, Schmidt et al. 2008).
5

6 High flows necessarily export relatively large volumes of sand in order to transfer sand
7 from the riverbed to high-elevation portions of sandbars (Wright, Schmidt et al. 2008). Within-
8 day fluctuations resulting from powerplant operations also increase the amount of sediment that
9 is transported downstream. As noted by Wright and Grams (2010), a steady flow will transport
10 less sand than an equivalent-volume fluctuating flow and retain more sandbars and beaches.
11 These dynamics are well understood, but the Sand Load Index does not fully address the
12 potential erosion of sandbars from intervening flows.
13

14 In order to understand effects on sediment resources, it is necessary to evaluate both the
15 indicators for sandbar growth potential (Sand Load Index) and the indicator for sand budget
16 (Sand Mass Balance Index). Both are affected by the number of HFEs. During a 20-year period,
17 there are a maximum of 40 possible HFEs (one in the fall, one in the spring each year) if there
18 were sufficient water and sediment volume (see Figure 4.3-5 in Section 4.3.3). Some alternatives
19 limit the maximum number of HFEs that can occur during the 20-year LTEMP period.
20 Alternatives A and B would have the fewest HFEs, because HFEs would not be conducted after
21 2020 under Alternative A, and HFEs are limited to one every other year under Alternative B;
22 consequently, these alternatives would have the lowest potential for building sandbars as
23 indicated by their relatively low Sand Load Index values. Alternatives F and G would have the
24 most HFEs, highest Sand Load Index values, and greatest potential to build bars. Alternatives C
25 and D would have slightly fewer HFEs than Alternatives F and G, while Alternative E would be
26 a bit lower because spring HFEs would not be implemented in the first 10 years of the LTEMP
27 period. These four alternatives show relatively large improvements in the potential to build
28 sandbars over Alternatives A and B. These differences among alternatives are discussed in
29 greater detail for each alternative in Section 4.3.3.
30

31 Alternatives C, D, and E include steady flows associated with HFEs (these steady flows
32 are also referred to as load-following curtailment). Alternative C would implement steady flows
33 before and after a spring HFE and fall HFE. Alternative D would only implement steady flows
34 after a fall HFE. Alternative E would only implement steady flows prior to a fall HFE. Although
35 load-following curtailment does help conserve sediment prior to and after an HFE, the effect is
36 relatively small because of the short duration of the curtailment, and the fact that two other
37 factors reduce sand transport during this time period regardless of curtailment—HFEs reduce the
38 average flow for the remainder of the month, and HFEs are applied in the lowest volume months
39 out of the year.
40

41 In contrast to the 277 mi of Marble Canyon and Grand Canyon, the 15-mi Glen Canyon
42 reach of the Colorado River receives very little sediment input. The Glen Canyon reach will
43 continue to be affected by the river during equalization flows, HFEs, or other high flow events
44 that continue to remove sediment within the reach. Sediment in the Glen Canyon reach is largely
45 a non-renewable resource because the first major sediment-bearing tributary is the Paria River,
46 16 mi below the dam. As a result of this, HFEs and other high flows do not generally contribute

1 to the replenishment or retention of beaches within the Glen Canyon reach, and pre-dam beach
2 sediments may continue to be lost.

3
4 Annual releases from Glen Canyon Dam affect the transport of sand on the bed of the
5 river as much as, if not more than, alternative-specific dam operations. For all alternatives, years
6 or periods of years that have a relatively low average annual release volume tend to transport less
7 sand, whereas those with higher average annual release volumes tend to transport more sand
8 downstream.

9
10 The only delta in Lake Mead that can be affected by LTEMP alternatives in terms of both
11 location and size is the Colorado River delta in Lake Mead; the tributary deltas in Lake Mead
12 will be affected in terms of position by dam operations but not in terms of size. Using historical
13 data on the GCMRC data portal (GCMRC 2015b), nearly half (approximately 46%) of the
14 suspended sand load reaching the gage at Diamond Creek (RM 225) since October 2002 can be
15 accounted for by suspended sand leaving Marble Canyon (RM 0 to 60). The other half of the
16 suspended sand reaching Diamond Creek comes from tributaries downstream of Marble Canyon,
17 most notably the Little Colorado River. The mass balance across alternatives varies by almost a
18 factor of 3 (Table 4.3-1), but this magnitude of variability is insignificant when compared to both
19 the average amount of sediment leaving Marble Canyon (10,000 kilotons per year) and the
20 average amount of sediment reaching Diamond Creek (22,000 kilotons per year). Therefore the
21 alternatives considered will have minimal impact on the size of the Colorado River delta in
22 Lake Mead.

23
24 The position of deltas in Lake Mead is directly affected by reservoir elevation. The
25 elevations of Lake Powell and Lake Mead are more sensitive to future hydrology and
26 corresponding annual releases from Glen Canyon Dam (Section 4.1) than to any alternative.
27 Figures 4.3-3 and 4.3-4 present the minimum, mean, and maximum monthly elevations relative
28 to full pool for 21 different hydrology traces across the seven alternatives. Pool elevations and
29 the effects on deltas are ultimately controlled by regional hydrologic conditions and will be
30 minimally affected by the alternatives. Alternative-specific impacts on reservoir deltas were not
31 further analyzed and are not discussed in Section 4.3.3.

32 33 34 **4.3.3 Alternative-Specific Impacts**

35
36 The impacts of LTEMP alternatives on sediment resources are summarized in
37 Table 4.3-1. Indicators of riverbed sand are mainly derived from modeling, and sandbar
38 indicators are the result of field surveys, modeling, and empirical data. Numerical values, based
39 on sources of information listed in Section 4.3.1, were used as indicators of impacts for all
40 sediment resources. Alternative-specific results for the number of HFEs, Sand Load Index
41 values, and Sand Mass Balance Index values are presented in Figures 4.3-5, 4.3-6, and 4.3-7,
42 respectively. Some uncertainty exists in the numerical values shown in these figures, in
43 Table 4.3-1, and in the subsequent discussion of alternatives. In general, however, uncertainty
44 would not affect relative differences among alternatives and would allow a comparison among
45 the alternatives because the uncertainties apply across all alternatives. This uncertainty does
46 mean that very small differences between alternatives may not be meaningful.

1 **TABLE 4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources**

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Least HFEs of any alternative would result in highest and mass balance, lowest potential for building sandbars.	The number of HFEs and bar building potential would be similar to those under Alternative A, but higher fluctuations would result in lower sand mass balance.	High number of HFEs would result in high bar-building potential, but lower sand mass balance than Alternative A.	High number of HFEs would result in high bar-building potential; sand mass balance comparable to Alternative A.	Number of HFEs would result in higher bar-building potential than Alternatives A but not other alternatives; lower sand mass balance than Alternative A.	Highest number of HFEs would result in highest bar-building potential, and lowest sand mass balance of all alternatives.	Second highest number of HFEs would result in second highest bar-building potential, and second lowest sand mass balance of all alternatives.
High Flow Events							
Average number of HFEs triggered in 20 years	5.5	7.2	21.3	19.3	17.1	19.3 (38.1) ^a	24.5
Maximum number of HFEs that could be implemented	14	10	40	38	30	40	40
Sandbars							
Sand Load Index value (20-year value)	0.21	0.23	0.54	0.53	0.46	0.56	0.58
Sand Load Index, relative to Alternative A (% change)	0%	10% increase	157% increase	152% increase	119% increase	167% increase	176% increase

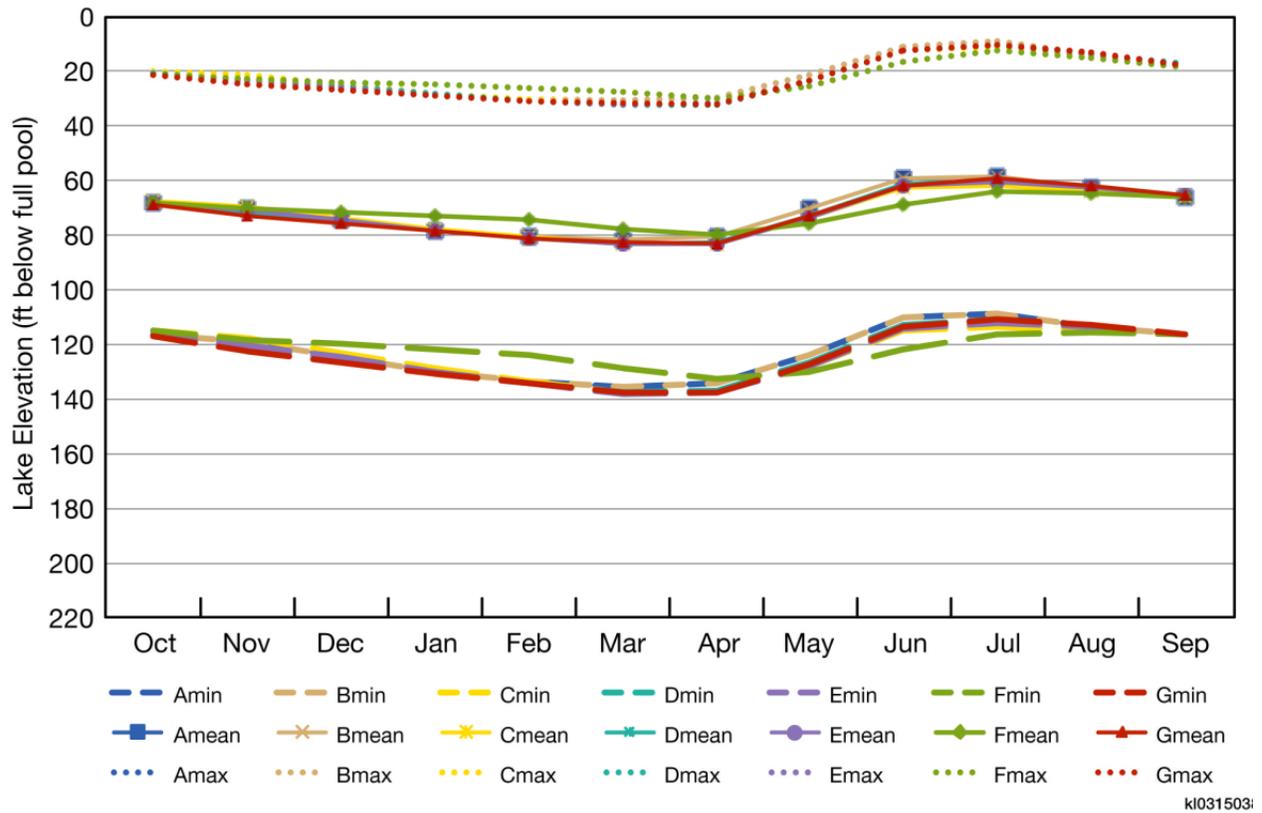
4-69

TABLE 4.3-1 (Cont.)

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Sediment Balance</i>							
Sand Mass Balance Index (kilotons) ^b	-1,010	-1,810	-2,140	-1,480	-1,980	-3,320	-2,840
Sand Mass Balance Index, relative to No Action (% change)	0%	80% decrease	112% decrease	47% decrease	96% decrease	230% decrease	182% decrease
Mean relative to average annual Paria sand load	-1.3	-2.4	-2.8	-2.0	-2.6	-4.4	-3.7
Interquartile range relative to annual Paria sand load	-4.9 to 1.5	-5.2 to 0	-5.3 to -0.6	-3.9 to 0	-5.3 to -0.2	-5.5 to -3.4	-5.9 to -1.8
Lake Mead Delta	The size and the position of the Colorado River Delta in Lake Mead is influenced more by regional hydrology and less by the dam operation alternatives considered in this analysis						

^a If alternative-defined annual spring flood (24 hr, 45,000 cfs flow if no sediment-triggered HFE) is counted, there would be a total of 38.1 HFES.

^b Sand mass at end of 20-year LTEMP period from RM 0 to 61 relative to start of LTEMP period; negative indicates net loss of sediment.



1

2 **FIGURE 4.3-3 Variation in Lake Powell Pool Elevation Relative to Full (3,700 ft) for 21 Hydrology**
 3 **Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are**
 4 **shown as dashed, solid, and dotted lines, respectively.)**

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4.3.3.1 Alternative A (No Action Alternative)

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Under Alternative A, HFEs would continue only for the period of the current HFE protocol, which will expire in 2020. In addition, spring HFEs would not occur until 2016 at the earliest. Therefore, Alternative A provides for a maximum of 14 HFEs during the 20-year period. On average, across 21 hydrology and 3 sediment time series (63 simulations total), there would be 5.5 HFEs triggered and implemented in the 20-year period (Figure 4.3-5), which is 39% of the maximum possible under Alternative A, and 14% of the overall maximum of 40 (one spring and one fall HFE every year).

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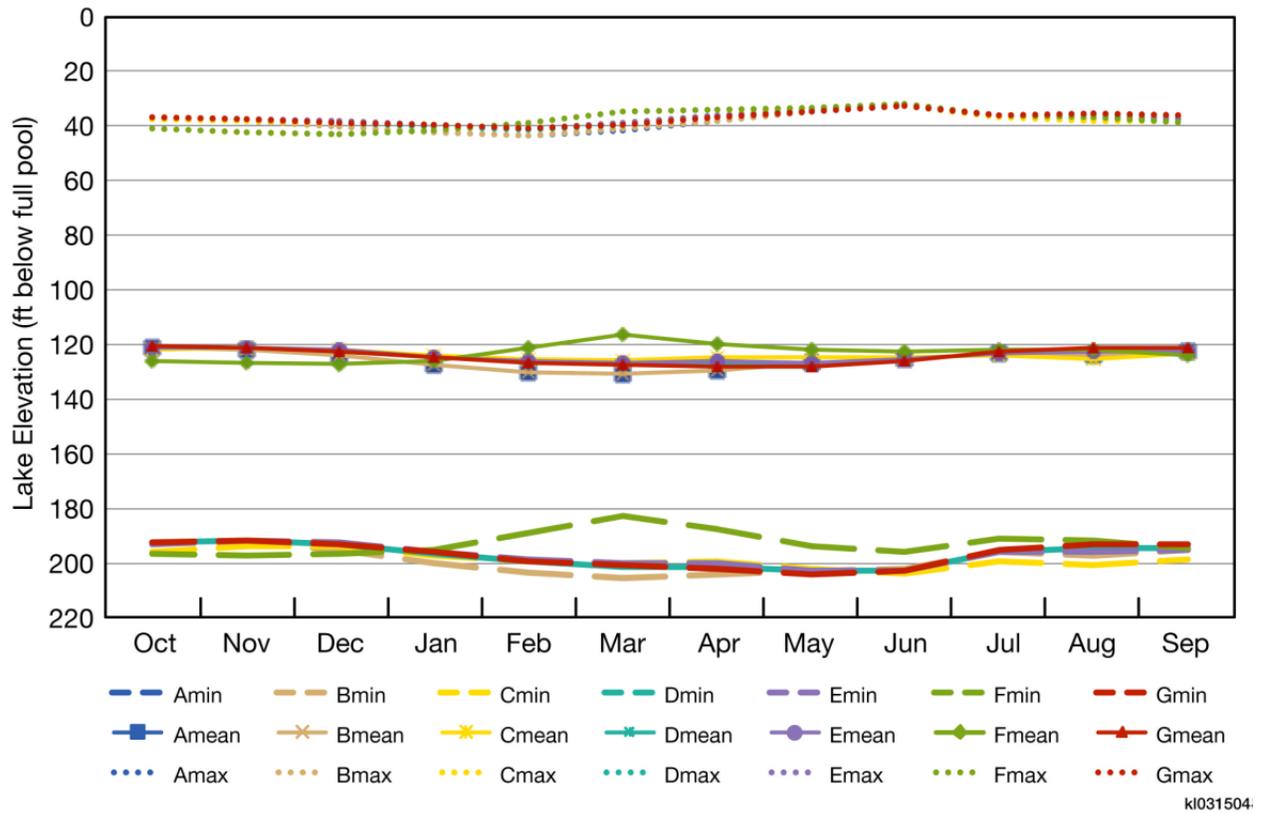
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The estimated 20-year average Sand Load Index for Alternative A is 0.21, with an inter-quartile range of 0.17–0.24 (Figure 4.3-6). This indicates that about 20% of the sediment transported over the 20-year LTEMP period is transported when discharge is >31,500 cfs, resulting in potential sandbar building. The Sand Load Index cannot currently be directly compared to sandbar response or size, but this value provides a baseline to which the other alternatives can be compared, and this alternative can be compared to dam operations that have been in place since 2012.



1

2 **FIGURE 4.3-4 Variation in Lake Mead Pool Elevation Relative to Full (1,229 ft) for 21 Hydrology**
 3 **Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are**
 4 **shown as dashed, solid, and dotted lines, respectively.)**

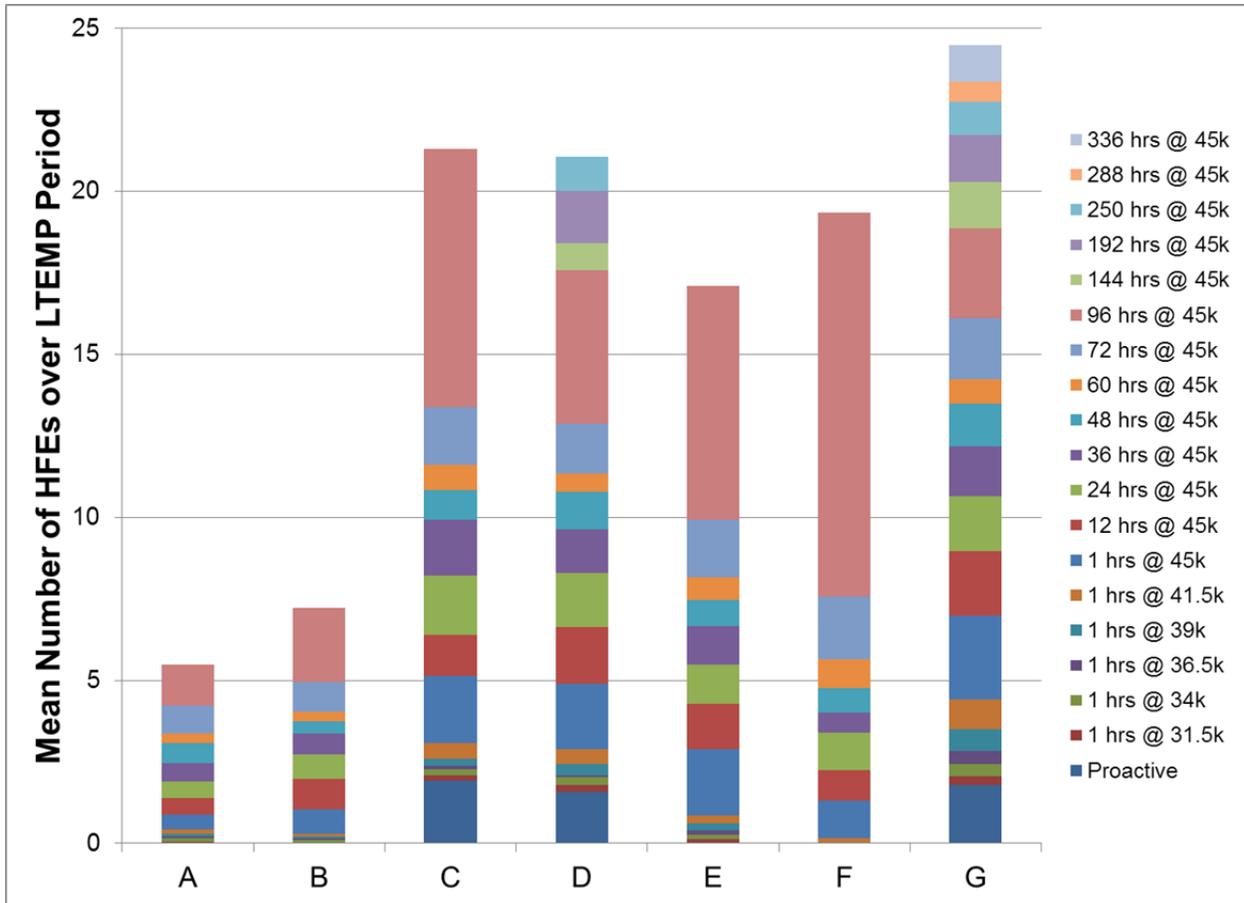
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7 Alternative A is a continuation of the current HFE protocol as defined in the 2011 EA
 8 (Reclamation 2011b). Three HFEs have been conducted under the HFE protocol; for these,
 9 sandbars increased in both volume and area as they did in response to the three preceding HFEs
 10 of 1996, 2004, and 2008 (Grams 2014). The Sand Load Index for Alternative A of 0.21 is the
 11 lowest of all alternatives (Table 4.3-1), indicating the lowest potential for building sandbars. This
 12 is due to the expiration of the HFE protocol in 2020, which in turn leads to the lowest number of
 13 HFEs for the simulation period of all alternatives. It is expected that bar building would continue
 14 through the HFE protocol window, and then bars would erode and decrease in size after 2020.

15

16 Under Alternative A, there would be an estimated average net loss of 1,010 kilotons of
 17 sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount
 18 is about 1.3 times the annual average sand input from the Paria River. About 46% of the
 19 63 conditions modeled resulted in a positive sand mass balance. This alternative retains, on
 20 average, the most sand in Marble Canyon of any alternative, but, as discussed above, the lowest
 21 potential for sandbar building after 2020.

22



1

2 **FIGURE 4.3-5 Number and Type of HFES Expected to Occur during the 20-Year LTEMP Period**
 3 **under the Seven Alternatives**

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6 In summary, Alternative A has the least HFES of any alternative and would result in the
 7 highest sand mass balance, but the lowest potential for building sandbars.

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 9

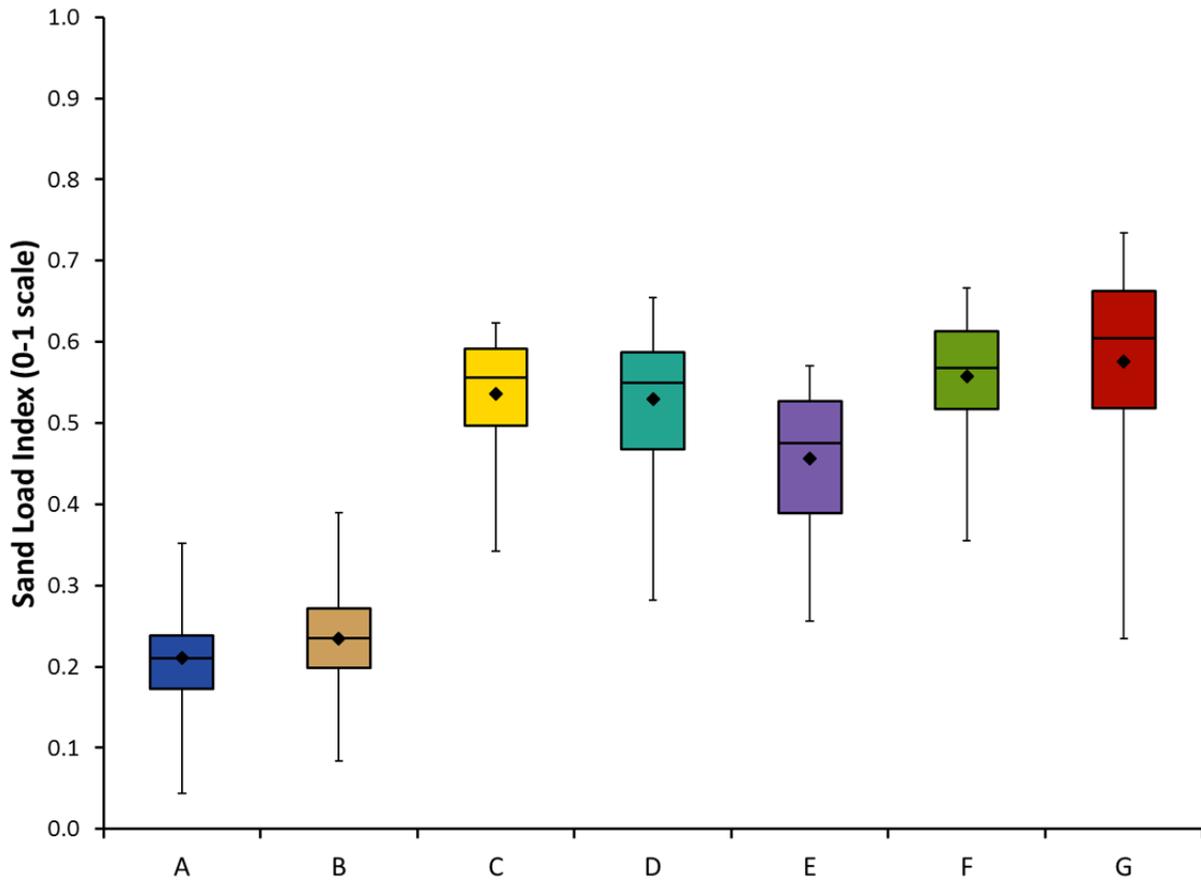
10 **4.3.3.2 Alternative B**

11

12 Under Alternative B, spring and fall HFES could be implemented during the 20-year
 13 LTEMP period, but HFES would not be implemented more often than once every 2 years.
 14 Therefore, Alternative B would allow a maximum of 10 sediment-triggered HFES during the
 15 20-year LTEMP period. On average, there would be 7.2 HFES triggered and implemented in the
 16 20-year period (Figure 4.3-5), which is 72% of the maximum possible under the alternative, and
 17 18% of the maximum of 40 possible under other alternatives.

18

19 The estimated 20-year average Sand Load Index for Alternative B is 0.23, with an inter-
 20 quartile range of 0.20–0.27 (Figure 4.3-6). The estimated average Sand Load Index for
 21 Alternative B is 10% greater than the Sand Load Index for Alternative A, suggesting slightly
 22 higher bar-building potential under Alternative B. The number of HFES and the Sand Load Index



1

2 **FIGURE 4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven**
 3 **Alternatives (Higher values indicate a greater potential for building sandbars. Note that**
 4 **diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper**
 5 **extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)**

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for this alternative are comparable to those under Alternative A. The largest difference is with the timing of the HFEs. The limitation to one HFE every 2 years in Alternative B implies that sandbars should persist throughout the simulation period, although the bars may become smaller during the periods between HFEs.

Under Alternative B, there would be an estimated average net loss of 1,810 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.4 times the annual average Paria River sand input. About 27% of the 63 conditions modeled resulted in a positive sand mass balance. The estimated average net loss of sand under Alternative B is a larger depletion (about 80% higher) compared to Alternative A. This difference can be attributed to the higher within-day fluctuations under Alternative B. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

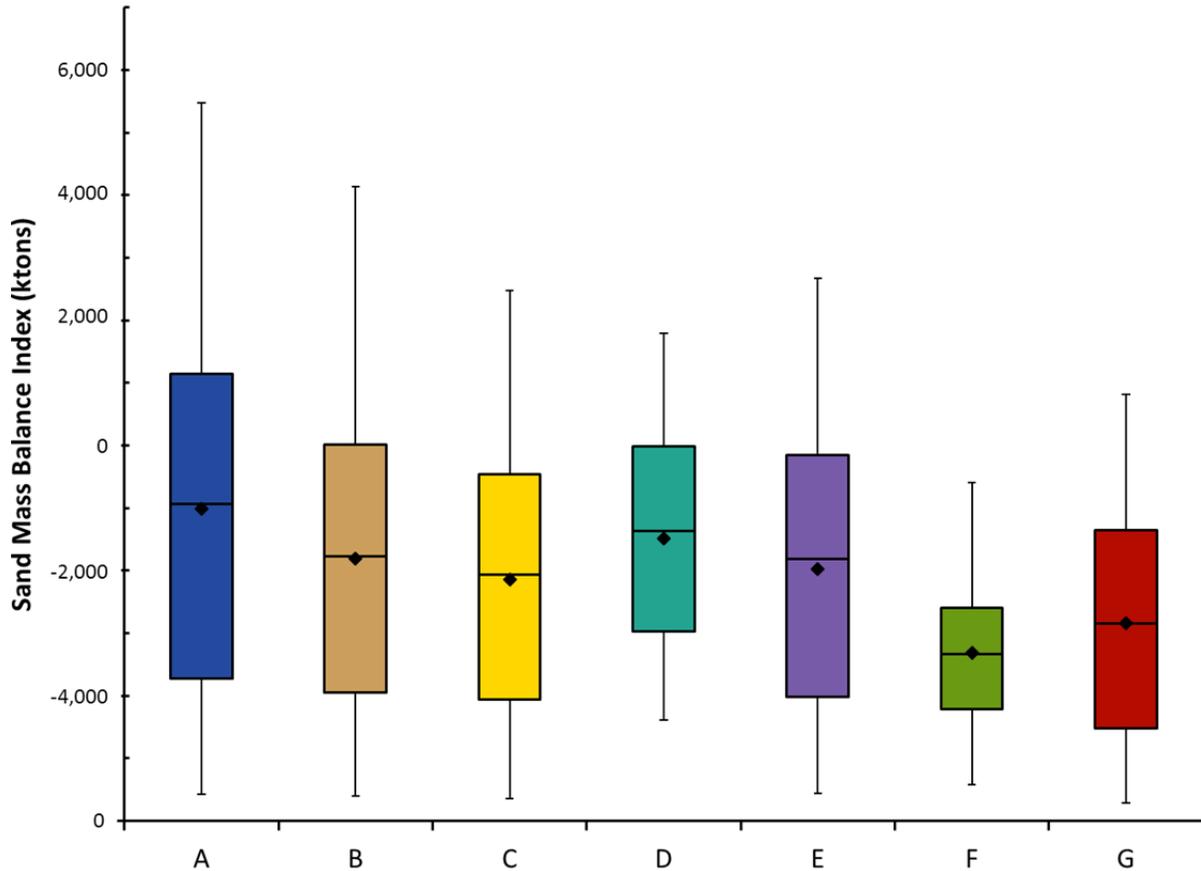


FIGURE 4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the Seven Alternatives (Higher values are considered better than lower values. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative B, including hydropower improvement flows, TMFs, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. Hydropower improvement flows and TMFs were modeled for Alternative B, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

Hydropower improvement flows would feature increased daily fluctuation ranges and ramp rates that would resemble those of operations at Glen Canyon Dam prior to the early 1990s (Section 2.2.2). Under Alternative B, this experimental operation would be implemented a maximum of four times over the 20-year LTEMP period in years with annual volumes of 8.23 maf or less. This additional fluctuation range would reduce the mean Sand Load Index to 0.22, which is still slightly higher than Alternative A, and would result in a sediment depletion of 2,400 kilotons. This larger depletion of sediment is a direct result of the larger daily fluctuation range. This depletion would affect the channel bed sediments and the sandbars, reducing their size.

1 The estimated effect of TMFs varies with hydrology and sediment conditions, but overall
2 there would be minimal adverse impact on sediment resources because TMFs would not change
3 monthly volumes. TMFs would be triggered by high levels of trout production, which are
4 stimulated by spring HFEs and other high flows (Section 4.4). The effect of HFEs on sediment
5 would be much greater than the effects of TMFs on sediment.
6

7 In summary, Alternative B has a sandbar-building potential that would be similar to that
8 under Alternative A, but higher fluctuations would result in lower sand mass balance.
9

10 **4.3.3.3 Alternative C**

11 Under Alternative C, spring and fall HFEs could be implemented in every year of the
12 20-year LTEMP period when triggered by sediment input. Therefore, Alternative C provides for
13 a maximum of 40 sediment-triggered HFEs. On average, there would be 21.3 HFEs triggered
14 and implemented (Figure 4.3-5), which is 53% of the maximum possible under the alternative,
15 and 53% of the overall maximum of 40.
16
17

18 The estimated 20-year weighted average Sand Load Index for Alternative C is 0.54, with
19 an inter-quartile range of 0.50–0.59 (Figure 4.3-6). The estimated average Sand Load Index
20 under Alternative C is 2.6 times greater than the Sand Load Index under Alternative A. This does
21 not imply that bars would be 2.6 times larger under this alternative compared to Alternative A,
22 but it does suggest that there would be substantially more bar-building potential under
23 Alternative C. Higher bar-building potential is a consequence of relatively frequent sediment-
24 triggered HFEs as well as proactive spring HFEs. The reduced fluctuations of Alternative C also
25 serve to conserve more sediment during normal operations, thus making more sediment available
26 for sandbar building during HFEs.
27

28 Under Alternative C, there would be an estimated average net loss of 2,140 kilotons of
29 sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount
30 is about 2.8 times the annual average Paria River sand input. About 22% of the 63 conditions
31 modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP
32 period. The estimated average net loss of sand under Alternative C is a larger depletion (about
33 112% higher) than that of Alternative A. This difference can be attributed to the higher number
34 of HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges
35 for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and
36 sediment input results in a greater impact on mass balance than operational characteristics of the
37 difference between the alternatives.
38

39 In addition to sediment-triggered spring and fall HFEs, there are several experimental
40 elements under Alternative C, including TMFs, proactive spring HFEs, extended-duration HFEs
41 (volume constrained), low summer flows, and mechanical removal of rainbow and brown trout
42 in the Little Colorado River reach. TMFs, proactive spring HFEs, long-duration HFEs, and low
43 summer flows were modeled for Alternative C, and their effects are described below (details are
44 presented in Appendix E). Mechanical removal of trout would have no effect on sediment
45 resources.
46

1 The estimated effect of TMFs varies with hydrology and sediment conditions, but overall
2 would be minimal on sediment resources (Appendix E). TMFs would be triggered by high levels
3 of trout production, which are stimulated by spring HFEs and other high flows (Section 4.4). The
4 effect of the HFEs on sediment would be much greater than the effect of a TMF.
5

6 Proactive spring HFEs are intended to utilize sediment on the riverbed to create bars in
7 advance of the erosive flows associated with high annual release years. Proactive spring HFEs
8 are expected to behave much the same as other HFEs by increasing the potential to build
9 sandbars and increasing downstream sediment transport. Proactive spring HFEs occur in high-
10 volume release years (≥ 10 maf), unless a sediment-triggered HFE had occurred earlier in the
11 spring. They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit
12 outage at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the
13 riverbed to create bars in advance of the erosive flows associated with high annual release years.
14 Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the
15 potential to build sandbars and increasing downstream sediment transport. The sediment models
16 do not have the capability of determining whether these proactive HFEs would be effective at
17 building and retaining sandbars, and field tests of this type of HFE are necessary to evaluate their
18 potential effectiveness. Under Alternative C, proactive spring HFEs would only be continued if
19 tests indicate a positive bar response.
20

21 Under Alternative C, extended-duration fall HFEs would be of equal release water
22 volume to those triggered under the existing HFE protocol but would be of lower magnitude
23 (e.g., 5-day 36,000 cfs HFE instead of a 4-day 45,000 cfs HFE). The difference in peak and
24 duration for a given release volume will have a relatively minor effect on sediment transport but
25 was not simulated for this analysis. Because of the nonlinear relationship between flow
26 magnitude and sediment transport, a longer duration, same-volume HFE would transport less
27 sand than a shorter duration, higher magnitude HFE. Such an HFE would also have a lower Sand
28 Load Index, and thus have a lower potential to build sandbars.
29

30 Implementation of low summer flows would require higher release volumes in the spring
31 to compensate for the lower releases from July through September. This increase in release
32 volume during the spring increases downstream transport of sediment. Due to the nonlinear
33 relationship between sediment transport and flow, this increase in the amount of sand transported
34 during the spring is more than the reduction in transport during low summer flows. The net effect
35 for the year is an increase in overall downstream sand transport, resulting in less sediment being
36 available for sandbar building during an HFE.
37

38 In summary, Alternative C would result in higher bar-building potential, but lower sand
39 mass balance than Alternative A.
40

41 **4.3.3.4 Alternative D (Preferred Alternative)** 42

43
44 Under Alternative D, fall HFEs could be implemented in every year of the 20-year
45 LTEMP period when triggered by sediment input, but spring HFEs would not be allowed in the
46 first 2 years of the LTEMP period. Therefore, Alternative D provides for a maximum of

1 38 sediment-triggered HFEs. On average, there would be 21.1 HFEs triggered and implemented
2 (Figure 4.3-5), which is 55% of the maximum possible under the alternative, and 53% of the
3 overall maximum of 40.

4
5 The estimated 20-year average Sand Load Index for Alternative D is 0.53, with an inter-
6 quartile range of 0.47–0.59 (Figure 4.3-6). The estimated average Sand Load Index under
7 Alternative D is 2.5 times greater than the Sand Load Index under Alternative A. This does not
8 imply that bars would be 2.5 times larger under this alternative compared to Alternative A, but it
9 does suggest that there would be substantially more bar-building potential under Alternative D.
10 Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs,
11 proactive spring HFEs, and extended-duration HFEs during much of the LTEMP period. The
12 reduced fluctuations of Alternative D also serve to conserve more sediment during normal
13 operations, thus making more sediment available for sandbar building during HFEs. In addition,
14 the more equal monthly volumes relative to those of Alternative A conserve more sediment
15 during normal operations, thus making more sediment available for sandbar building during
16 HFEs.

17
18 Under Alternative D, there would be an estimated average net loss of 1,490 kilotons of
19 sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount
20 is about 2.0 times the annual average Paria River sand input. About 25% of the 63 conditions
21 modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP
22 period. The estimated average net loss of sand under Alternative D is a larger depletion (about
23 46% higher) than that of Alternative A. This difference can be attributed to the higher number of
24 HFEs and extended-duration HFEs that would be implemented under this alternative. Comparing
25 the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that
26 future hydrology and sediment input results in a greater impact on the mass balance than the
27 difference between the alternatives.

28
29 In addition to sediment-triggered spring and fall HFEs, there are several experimental
30 elements under Alternative D, including TMFs, proactive spring HFEs, extended-duration HFEs,
31 low summer flows, benthic invertebrate flows, and mechanical removal of rainbow and brown
32 trout in the Little Colorado River reach. TMFs, proactive spring HFEs, benthic invertebrate
33 flows, and low summer flows were modeled as an integral part of Alternative D, and their effects
34 are described below (details are presented in Appendix E). Mechanical removal of trout would
35 have no effect on sediment resources.

36
37 The estimated effect of TMFs varies with hydrology and sediment conditions, but overall
38 would be minimal on sediment resources. TMFs would be triggered by high levels of trout
39 production, which are stimulated by spring HFEs and other high flows (Section 4.5). The effect
40 of the HFEs on sediment would be much greater than the effect of a TMF.

41
42 All HFEs, including proactive spring HFEs, have the largest impact on sediment
43 resources relative to other experimental elements. By definition, proactive spring HFEs are HFEs
44 that occur in 10-maf or greater annual release years when there is limited spring sediment input.
45 They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit outage
46 at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the riverbed to

1 create bars in advance of the erosive flows associated with high annual release years. Proactive
2 spring HFEs are expected to behave much the same as other HFEs by increasing the potential to
3 build sandbars and increasing downstream sediment transport. The sediment models do not have
4 the capability of determining whether these HFEs would be effective, and field tests of this type
5 of HFE would be needed to evaluate their potential effectiveness. Under Alternative D, proactive
6 spring HFEs would only be continued if tests indicate a positive bar response.
7

8 Under Alternative D, extended-duration fall HFEs (up to 250 hr) would be implemented
9 during the 20-year LTEMP period, depending on sediment conditions. Modeling demonstrated
10 that extended-duration HFEs would have substantial effects on both the Sand Load Index
11 (increases index value) and the Sand Mass Balance Index (decreases index value). Extended-
12 duration HFEs have never been performed in sediment-enriched conditions. The models and
13 existing data suggest that these HFEs could result in substantially greater sandbar building.
14 Extended-duration HFEs would result in higher Sand Load Index values, and consequently
15 higher bar-building potential, than more typical 96-hour or shorter HFEs, but would also
16 transport more sand out of the Marble Canyon reach. Extended-duration HFEs would be tested in
17 up to 4 years during the LTEMP period and only when sufficient sand input from the Paria River
18 would support the extended flow.
19

20 Implementation of low summer flows requires higher release volumes in the spring to
21 compensate for the lower releases from July through September. This increase in release volume
22 during the spring increases downstream transport of sediment. Due to the nonlinear relationship
23 between sediment transport and flow, this increase in the amount of sand transported during the
24 spring is more than the reduction in transport during low summer flows. The net effect for the
25 year is an increase in overall downstream sand transport, resulting in less sediment being
26 available for sandbar building during an HFE.
27

28 Sustained low flows for invertebrate production would consist of steady flows during the
29 weekends of May through August. This flow action is expected to have a relatively minor effect
30 on Sand Load Index and Sand Mass Balance Index values.
31

32 After modeling was completed for Alternative D, discussions with stakeholders resulted
33 in some modifications to the alternative (see Section 2.2.4). Monthly volumes for August were
34 simulated at 750 kaf, but the August volume was adjusted to 800 kaf, with this increase being
35 offset by decreased volumes in May and June (25 kaf decrease in each month). Additional
36 changes to the alternative made since the completion of modeling included a ban on sediment-
37 triggered spring HFEs in the same water year as an extended-duration fall HFE, elimination of
38 load-following curtailment prior to fall HFEs, and load-following curtailment until the end of the
39 month in which fall HFEs occur (as opposed to December 1). On average, 3.5 extended-duration
40 HFEs were triggered in 20 years (there is a maximum of 4 that are allowed during any given
41 simulation). Of the 3.5 extended-duration HFEs, 1.3 were followed by sediment-triggered spring
42 HFEs. These changes in the alternative are not expected to result in significant changes in the
43 impacts of Alternative D on sediment resources and would not alter the relative ranking of
44 alternatives.
45

1 In summary, Alternative D would result in higher sandbar-building potential than
2 Alternative A, while preserving more sand than all alternatives except Alternative A.
3
4

5 **4.3.3.5 Alternative E**

6

7 Under Alternative E, fall HFES could be implemented during the 20-year LTEMP period,
8 but spring HFES would not be implemented in the first 10 years of the program. Therefore,
9 Alternative E provides for a maximum of 30 HFES during the 20-year period. On average,
10 17.1 HFES would be triggered and implemented (Figure 4.3-5), which is 57% of the maximum
11 possible under the alternative, and 43% of the overall maximum of 40.
12

13 The estimated 20-year average Sand Load Index for Alternative E is 0.46, with an inter-
14 quartile range of 0.39–0.53 (Figure 4.3-6). The estimated average Sand Load Index is 2.2 times
15 greater than for Alternative A. This does not imply that bars would be 2.2 times larger under this
16 alternative compared to Alternative A, but it does suggest that there would be substantially more
17 bar-building potential under Alternative E. Higher bar-building potential is a consequence of the
18 potential for sediment-triggered HFES throughout the LTEMP period under this alternative. The
19 more equal monthly volumes relative to those of Alternative A also conserve more sediment
20 during normal operations, thus making more sediment available for sandbar building during
21 HFES.
22

23 Under Alternative E, there would be an estimated average net loss of 1,980 kilotons of
24 sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount
25 is about 2.6 times the annual average Paria River sand input. The estimated average net loss of
26 sand under Alternative E is a larger depletion (about 96% higher) than that of Alternative A. This
27 difference can be attributed to the higher number of HFES that would be implemented under this
28 alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A
29 (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on
30 the mass balance than the difference between the alternatives.
31

32 In addition to sediment-triggered spring and fall HFES, there are several experimental
33 elements under Alternative E, including TMFs, low summer flows, and mechanical removal of
34 rainbow and brown trout in the Little Colorado River reach. TMFs and low summer flows were
35 modeled for Alternative E, and their effects are described below (details are presented in
36 Appendix E). Mechanical removal of trout would have no effect on sediment resources.
37

38 The estimated effect of TMFs varies with hydrology and sediment conditions, but overall
39 would be minimal on sediment resources. TMFs would be triggered by high levels of trout
40 production, which are stimulated by spring HFES and other high flows (Section 4.4). The effect
41 of the HFES on sediment would be much greater than the effect of a TMF.
42

43 Implementation of low summer flows would require higher releases of water in the spring
44 to compensate for the lower releases from July through September. This increase in release
45 volume during the spring increases downstream transport of sediment. Because sediment
46 transport has a nonlinear relationship with flow, the increase in sand that is transported during

1 the spring is of larger magnitude than the decrease in sediment transport during the summer. The
2 net effect over the year is an increase in overall downstream sand transport, resulting in less
3 sediment being available for transport during an HFE.

4
5 In summary, Alternative E would result in higher bar-building potential than
6 Alternatives A and B, but not the other alternatives, and would have lower sand mass balance
7 than Alternative A.

8 9 10 **4.3.3.6 Alternative F**

11
12 Under Alternative F, spring and fall HFEs could be implemented in every year of the
13 20-year LTEMP period when triggered by sediment input. Therefore, Alternative F provides for
14 a maximum of 40 sediment-triggered HFEs. Under the alternative, in years when a spring HFE
15 was not triggered, there would be a 24-hour 45,000 cfs release in the beginning of May,
16 regardless of the availability of sediment. On average, 19.3 sediment-triggered HFEs would be
17 called for in the 20-year LTEMP period (Figure 4.3-5), which is 48% of the maximum possible
18 under the alternative, and 48% of the overall maximum of 40 (one spring and one fall HFE every
19 year). If the alternative-prescribed annual May events in years without sediment-triggered HFEs
20 are counted, there are on average 38.1 HFEs during the 20-year LTEMP period.

21
22 The estimated 20-year average Sand Load Index for Alternative F is 0.56, with an inter-
23 quartile range of 0.52–0.61 (Figure 4.3-6). The estimated average Sand Load Index under
24 Alternative F is 2.7 times greater than the Sand Load Index under Alternative A. This does not
25 imply that bars would be 2.7 times larger under this alternative compared to Alternative A, but it
26 does suggest that there would be substantially more bar-building potential under Alternative F.
27 Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs,
28 as well as a 24-hour 45,000 cfs release in May in years when a spring HFE is not triggered by
29 sediment input.

30
31 Under Alternative F, there would be an estimated average net loss of 3,320 kilotons of
32 sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount
33 is about 4.4 times the annual average Paria River sand input, about 230% higher than under
34 Alternative A. This is the largest depletion associated with any of the alternatives, resulting from
35 the high frequency of HFEs, including an alternative-prescribed flood every spring regardless of
36 tributary sediment inflows, as well as extended elevated flow releases (approximately 20,000 cfs)
37 for the duration of May and June. None of the 63 conditions modeled resulted in a positive mass
38 balance at the end of the LTEMP period. Comparing the inter-quartile ranges for this alternative
39 and for Alternative A (Figure 4.3-7) suggests that that future hydrology and sediment input
40 results in a lesser impact on the mass balance than the alternative.

41
42 Other than sediment-triggered spring and fall HFEs, no experimental elements are
43 identified under this alternative.

44
45 In summary, Alternative F has the highest number of HFEs and would result in the
46 highest bar-building potential, but the lowest sand mass balance of all alternatives.

1 **4.3.3.7 Alternative G**
2

3 Under Alternative G, spring and fall HFES could be implemented in every year of the
4 20-year LTEMP period when triggered by sediment input. Therefore, Alternative G provides for
5 a maximum of 40 sediment-triggered HFES. On average, 24.5 HFES would be triggered and
6 implemented (Figure 4.3-5), which is 61% of the maximum possible under the alternative, and
7 61% of the overall maximum of 40. This is the only alternative that would allow for HFE
8 durations of up to 336 hr at the 45,000 cfs peak flow rate, and there would be no limit to the
9 number of extended-duration HFES as long as they could be supported by sediment inputs.
10

11 The estimated 20-year average Sand Load Index for Alternative G is 0.58, with an inter-
12 quartile range of 0.52–0.66. This is the alternative with the highest average Sand Load Index.
13 The estimated average Sand Load Index for Alternative G is 2.8 times greater than the Sand
14 Load Index for Alternative A. This does not imply that bars will be 2.8 times larger under this
15 alternative as compared to Alternative A, but it does suggest that there would be significantly
16 more bar-building potential under Alternative G. Higher bar-building potential is a consequence
17 of relatively frequent sediment-triggered HFES, proactive spring HFES, and extended-duration
18 HFES during the entire LTEMP period. The lack of daily fluctuations under Alternative G and
19 equal monthly volumes also would conserve more sediment during normal operations, thus
20 making more sediment available for transport during HFES.
21

22 Under Alternative G, there would be an estimated average net loss of 2,840 kilotons of
23 sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount
24 is about 3.7 times the annual average Paria River sand input. About 6% of the 63 conditions
25 modeled resulted in a positive mass balance at the end of the LTEMP period. The estimated
26 average net loss of sand under Alternative G represents a depletion that is about 182% greater
27 than that under Alternative A. This difference can be attributed to the higher number of HFES
28 and extended-duration HFES that would be implemented under this alternative. Comparing the
29 inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future
30 hydrology and sediment input results in as much impact on the mass balance as the alternative
31 definition.
32

33 In addition to sediment-triggered spring and fall HFES, there are several experimental
34 elements under Alternative G, including TMFs, proactive spring HFES, extended-duration HFES,
35 and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs,
36 proactive spring HFES, and extended-duration HFES were modeled for Alternative G, and their
37 effects are described below (details are presented in Appendix E). Mechanical removal of trout
38 would have no effect on sediment resources.
39

40 The estimated effect of TMFs varies with hydrology and sediment conditions, but overall
41 would have a minimal effect on sediment resources. TMFs would be triggered by high levels of
42 trout production, which are stimulated by spring HFES and other high flows (Section 4.5). The
43 effect of the HFES on sediment would be much greater than the effect of a TMF.
44

45 All HFES, including proactive spring HFES, have the largest impact on sediment
46 resources relative to other experimental elements. Proactive spring HFES are expected to behave

1 much the same as other HFEs by increasing the potential to build sandbars and increasing
2 downstream sediment transport. The sediment models do not have the capability of determining
3 whether these HFEs would be effective, and field tests of this type of HFE would be needed to
4 evaluate their potential effectiveness. Under Alternative G, proactive spring HFEs would only be
5 continued if tests indicate a positive bar response.

6
7 In this alternative, extended-duration HFEs may be up to 336 hr long and would be
8 triggered by the appropriate sediment conditions. Modeling demonstrated that extended-duration
9 HFEs would have important effects on both the Sand Load Index (increases index value) and the
10 Sand Mass Balance Index (decreases index value). Extended-duration HFEs have never been
11 performed in sediment-enriched conditions. The models and existing data suggest that these
12 HFEs could result in substantially greater sandbar building.

13
14 In summary, Alternative G has the second-highest number of HFEs and would result in
15 the second-highest bar-building potential and the second-lowest sand mass balance of all
16 alternatives.

17 18 19 **4.4 NATURAL PROCESSES**

20
21 The Colorado River Ecosystem is defined
22 as the Colorado River mainstem corridor and
23 interacting resources in associated riparian and
24 terrace zones located primarily from the forebay
25 of Glen Canyon Dam to the western boundary of
26 Grand Canyon National Park (GCNP). It includes
27 the area where dam operations impact physical,
28 biological, recreational, cultural, and other
29 resources. An important objective of
30 management of the Colorado River Ecosystem is
31 the ability to sustain healthy populations of
32 native plants and animals. As described in
33 Chapter 3, management policies identified by the
34 NPS (NPS 2006d) state that “whenever possible,
35 natural processes will be relied upon to maintain
36 native plants and animals and influence natural fluctuations in populations of these species.”

Issue: How do alternatives affect physical conditions which drive the natural processes that support native plants and animals, and their habitats, in Glen and Grand Canyons?

Impact Indicators:

- Flow characteristics, including monthly release patterns and within-day variability
- Seasonal water temperature patterns
- Sediment mass balance and sandbar building potential
- Water quality (nutrients and turbidity)

37
38 Major physical drivers of natural processes in the Colorado River Ecosystem are flow,
39 water temperature, sediment transport, and water quality (including nutrients and turbidity). The
40 nature of these parameters directly and/or indirectly determines the abundance, condition, and
41 status of habitats for native and nonnative plants and animals in the ecosystem below the dam.

42
43 The natural processes within the Colorado River Ecosystem reflect historic changes to the
44 system (Chapter 3). The existing facilities and laws and regulations further constrain the options
45 for fully restoring the original natural processes within the canyon. It is not possible to operate
46 the dam in a manner that could restore to pre-dam conditions the physical parameters that drive

1 natural processes. Nonetheless, physical and chemical parameters that influence natural
2 processes and native and nonnative species communities may be affected differently by each of
3 the LTEMP alternatives.
4

6 **4.4.1 Analysis Methods**

7
8 The range of variability of physical parameters in the Colorado River Ecosystem is
9 constrained by the operational limits of the dam, but varies by alternative. It is assumed that the
10 natural abundance, diversity, and genetic and ecological integrity of plant and animal species
11 native to the river will be influenced by the physical riverine conditions that are produced under
12 each alternative.
13

14 A conceptual model showing expected linkages among dam releases, physical conditions,
15 habitats, and affected ecological resources is shown in Figure 4.4-1. As shown, the primary
16 effects of any alternative on plant and animal species below the dam will be a direct function of
17 the changes in the physical conditions (e.g., sediment transport, water temperature) that would
18 occur under each alternative; how those alternative-specific changes affect habitat quality,
19 quantity, and stability; and how aquatic and terrestrial biota will respond to those changes. Thus,
20 the evaluation of how each alternative may affect natural processes below Glen Canyon Dam
21 was based on the examination of how selected physical parameters would differ under each
22 alternative. These differences in physical parameters were assessed as described in Sections 4.2.1
23 (for temperature-, flow-, and water-quality-related indicators) and 4.3.1 (for sediment-related
24 indicators). These evaluations were then considered together to provide a qualitative
25 determination of how natural processes in the river below Glen Canyon Dam would be affected
26 under each alternative. Table 4.4-1 identifies the role of each of the physical parameters in
27 influencing natural processes in the Colorado River Ecosystem.
28
29

30 **4.4.2 Summary of Impacts**

31
32 One of the most important factors affecting ecological resources (i.e., native plants and
33 animals and their habitats) in the Colorado River Ecosystem is the interannual variability in the
34 hydrology of the system as driven by weather patterns and climatic conditions. Under a natural
35 hydrograph, physical conditions in the river would include a hydrograph with peak flows and
36 volumes in later spring/early summer, daily flows ranging on average from 1,000 cfs in winter to
37 >92,000 cfs in spring and summer, and daily fluctuations only in response to precipitation events
38 and tributary inflows (Section 3.2.2.2). Water temperatures would range from near freezing in
39 winter to 30°C (86°F) in the late summer, and turbidity would be high throughout the year
40 (Section 3.2.3.2). It is under such conditions that natural processes would act to develop, support,
41 and maintain the original native ecosystems of the river.
42

43 The nature, magnitude, pattern, and duration of flows, as well as water temperatures and
44 water quality, in the Colorado River Ecosystem are so strongly constrained by the presence of
45 the dam and by the existing laws and regulations that govern conveyance of water between the
46 Upper and Lower Basins that it is not possible for any of the alternatives to restore natural

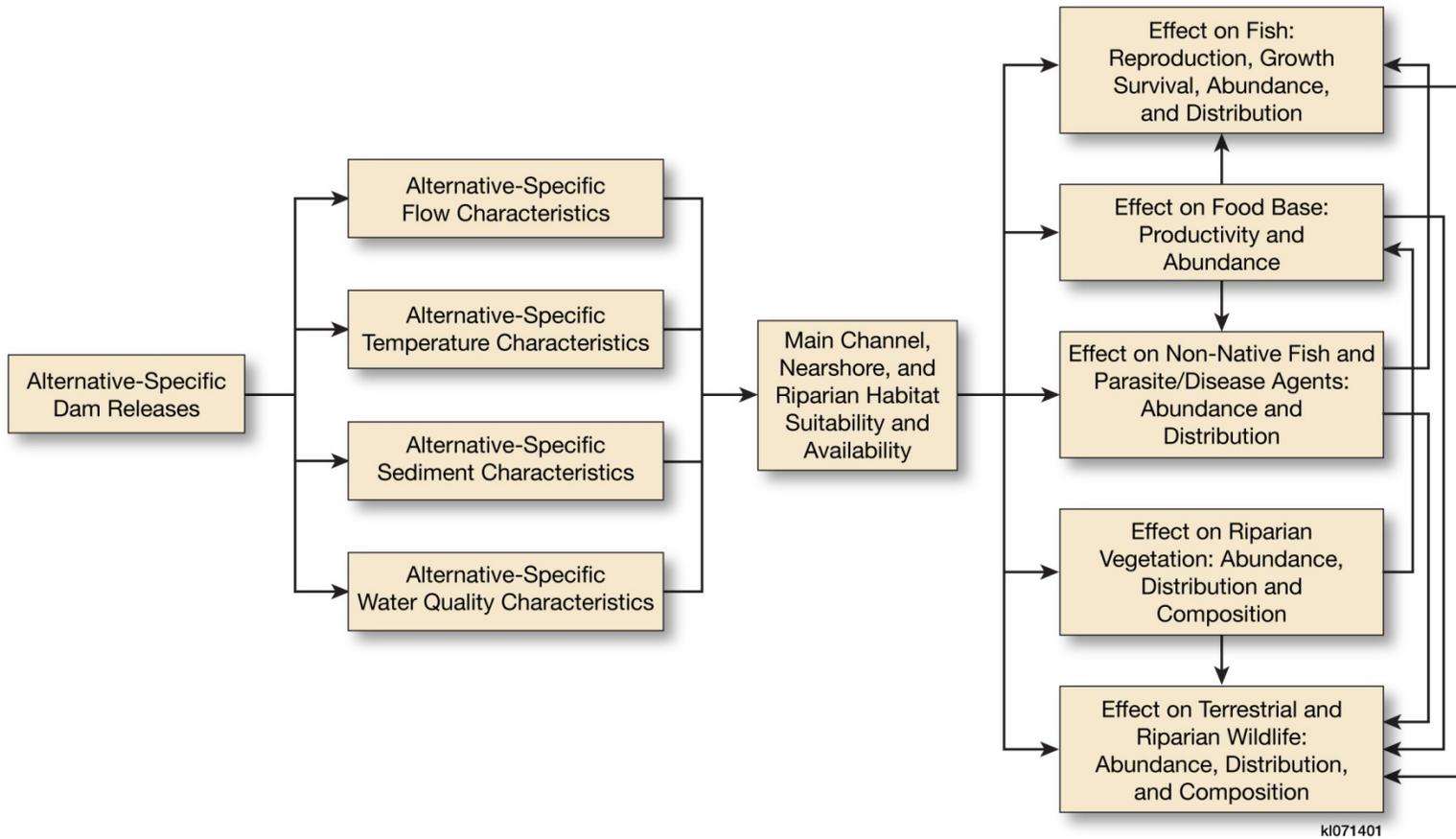


FIGURE 4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats, and Ecological Resources in the Colorado River Ecosystem

4-85

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1 **TABLE 4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative**

Indicator	Role in Affecting Natural Processes
<i>Flow-Related Indicators</i>	
Peak and base flows	The frequency, magnitude, duration, and timing of peak and base flows directly affect aquatic and riparian habitats and their biota, as well as other physical factors such as water temperature and sediment transport, deposition, and loss, which in turn affect aquatic and riparian habitats, native fish and aquatic invertebrates, the aquatic food base, and riparian vegetation and wildlife. There are also direct effects from peak and base flows on vegetation.
Monthly release volumes	The magnitude and pattern of monthly release volumes affect sediment transport and physical conditions that influence important life history parameters of aquatic biota, such as egg laying and hatching in fish, as well as the quality and quantity of mainstem and nearshore aquatic habitats and riparian habitats along the main channel.
Mean daily flows	The magnitude and pattern of daily flows (including ramp rates) affect main channel and nearshore aquatic habitats, riparian habitats, and the biota that rely on these habitats.
Mean daily flow fluctuations	Daily flow fluctuations (including ramp rates) affect sediment transport and directly affect daily changes in stage, which in turn affect mainstem riparian vegetation, main channel and nearshore aquatic habitat stability, and productivity and distribution of the aquatic food base.
<i>Temperature-Related Indicators</i>	
Mean main channel water temperatures	Water temperatures affect reproduction, growth, and survival of fish and aquatic invertebrates in main channel and nearshore habitats, as well as productivity of the aquatic food base.
<i>Sediment-Related Indicators</i>	
Sediment transport and deposition	These sediment parameters affect main channel and nearshore aquatic habitats as well as riparian habitats, the biota that rely on these habitats, and the aquatic food base.
Elevation of annual sediment deposition	Elevation of annual sediment deposits affects distribution, abundance, and composition of riparian vegetation and terrestrial wildlife habitat.
<i>Water-Quality-Related Indicators</i>	
Turbidity	Turbidity affects predator-prey relationships among aquatic biota, as well as primary productivity.
Nutrients	Nutrients affect aquatic habitat quality for fish, invertebrates, and the aquatic food base.

2

1 processes in the system to pre-dam conditions. In addition to their effects on flow, Glen Canyon
2 Dam and Lake Powell trap most of the sediment from the Upper Basin that would normally be
3 transported into and through the Colorado River in Glen and Grand Canyons. The dam also
4 serves as a physical barrier to the movement of riverine organisms between the Upper and Lower
5 Basins. In this context, the LTEMP alternatives have relatively similar effects and have the
6 potential to produce only relatively small changes in current conditions that could improve
7 natural processes.
8

9 Regardless of which alternative is implemented, there would be little change from current
10 conditions with regard to peak or base flows (maximum daily flows up to 25,000 cfs, minimum
11 daily flows 5,000 to 8,000 cfs), mean Glen Canyon Dam release water temperature, overall
12 turbidity or nutrient concentrations, or the maximum height of annual sediment deposition
13 (elevation of 45,000 cfs flows). Thus, natural processes dependent on these physical factors
14 would not differ from current operations, and these are not discussed further in the analysis
15 below.
16

17 Despite these limitations, LTEMP alternatives do vary to some extent in some physical
18 parameters that directly affect natural processes and the native plants, animals, and habitats
19 controlled by those processes. Differences among alternatives as related to natural processes
20 were inferred on the basis of potential differences among the alternatives in physical indicators
21 (Table 4.4-2).
22

23 Some changes in natural processes may be expected under all alternatives, as reflected by
24 expected changes in one or more of the physical indicators, but these changes are expected to be
25 relatively modest compared to current conditions, especially for the fluctuating flow alternatives
26 (Alternatives B–E) (Table 4.4-2). By altering the monthly release patterns and eliminating
27 within-day fluctuations, the two steady-flow Alternatives F and G would result in the greatest
28 changes to natural processes relative to those under current conditions.
29

30 Alternatives with greater daily flow fluctuations (Alternatives B and E) could result in
31 reductions in nearshore habitat stability compared to the other alternatives, and thus have more
32 of an effect on aquatic and riparian biota in nearshore habitats (Sections 4.5, 4.6, and 4.7).
33

34 Compared to Alternative A, natural processes influenced by sediment dynamics could be
35 affected under Alternatives B through G, as the potential for bar building (as inferred from Sand
36 Load Index estimates) ranges from 11% to 173% greater than under Alternative A. In contrast,
37 sediment depletion from Marble Canyon (as inferred from Sand Mass Balance Index estimates)
38 ranges from 47% to 230% greater than under Alternative A. This sediment depletion, however,
39 would be balanced by greater deposition of sediment in areas above the normal range of flows
40 where that sediment could benefit terrestrial ecosystems. This redistribution of sediment would
41 restore, albeit to a limited extent, the natural pattern of sediment distribution.
42

43 Alternative F may have the greatest effect of all alternatives on natural processes.
44 Alternative F is the only alternative with a monthly release pattern that has been seasonally
45 adjusted to more closely follow the seasonal pattern of inflow, and (along with Alternative G)
46 has the least daily flow fluctuations, which would result in more stable and presumably higher
47

1 **TABLE 4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated with Flow, Water Temperature, Water**
 2 **Quality, and Sediment Resources^a**

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Existing natural processes related to flow, water temperature, water quality and sediment resources would continue, but replenishment of sandbars would diminish after 2020 when HFEs would cease.	Compared to Alternative A, most natural processes would be unchanged, but there would be less nearshore habitat stability as a result of greater within-day fluctuations.	Compared to Alternative A, there would be more nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer and fall water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Similar to Alternative C.	Similar to Alternative B for flow-related processes, but more similar to C for water temperature and sediment-related processes.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within seasonal variability; sediment-related processes similar to Alternative C.	Compared to other alternatives, there would be little variability in flow, water temperature, or water quality processes; Alternative G would have the highest potential of any alternative to build sandbars and retain sand in the system.

4-88

3
4

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Flow-Related Indicators</i>							
Daily maximum and minimum flows	No change from the current daily maximum of 25,000 cfs, and daily minimum of 5,000 to 8,000 cfs.	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Mean monthly release volume and mean daily flow	No change from current conditions, with highest mean monthly release volumes and mean daily flows in winter and summer.	Same as Alternative A	Higher mean monthly volumes and mean daily flows in winter, spring, and summer with lowest volumes in late summer and autumn favoring conservation of sediment inputs during the monsoon period.	Relatively even monthly volumes and mean daily flows favoring conservation of sediment year-round.	Relatively even monthly volumes and mean daily flows, but lower volumes in late summer favoring conservation of sediment inputs during the monsoon period.	Monthly volumes and daily flows seasonally adjusted to more closely match monthly pattern of inflows with high spring flows and low summer through winter flows.	Monthly volumes and daily flows are approximately equal, favoring conservation of sediment year-round.
Mean daily changes in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs.	Mean daily change higher in all months (range about 2,500 to 12,000 cfs, and even higher with hydropower improvement flows), which could reduce stability of nearshore habitats.	Mean daily change lower in all months (about 1,300 to 6,200 cfs), which could increase stability of nearshore habitats.	Mean daily change slightly higher in Oct. through Jun., which could slightly reduce nearshore habitat stability. Mean daily change in other months comparable to Alternative A (range about 2,700 to 7,600 cfs).	Mean daily change higher in all months but Sept. and Oct. (range about 1,100 to 9,600 cfs), which could reduce stability of nearshore habitats.	Steady flows will increase stability of nearshore habitats.	Steady flows will increase stability of nearshore habitats.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Temperature-Related Indicators							
Mean Glen Canyon Dam release water temperature	Mean seasonal release temperatures are expected to be about 9.9°C in winter (about 9.7–10.2°C), 9.0°C in spring (8.8–9.2°C), 11.3°C (10.9–11.4°C) in summer, and 12.2°C (11.9–12.4°C) in fall.	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A
Mean seasonal main channel water temperature and downstream warming	No change from current conditions. Mean seasonal water temperatures between Lees Ferry and Diamond Creek range 10.0–10.6°C in winter, 9.3–13.5°C in spring, 11.6–17.2°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.6°C.	Same as Alternative A	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.2°C in spring, 11.7–17.6°C in summer, and 12.3–15.9°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.5°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.3°C in spring, 11.6–17.6°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 6.0°C.	Mean seasonal water temperatures range 9.9–10.6°C in winter, 9.5–12.5°C in spring, 11.9–18.6°C in summer, and 12.3–16.0°C in fall. Greatest amount of winter (0.9°C), summer (6.7°C), and fall (3.7°C) warming, and least amount of spring (3.0°C) warming of all alternatives.	Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.8°C in summer, and 12.4–15.3°C in fall. Second highest summer warming (6.2°C) of all alternatives.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Sediment-Related Indicators</i>							
Sediment transport and deposition	No change from current conditions with reduction of sandbar area and volume after HFE protocol expires in 2020. 20-yr average SLI of 0.21 and SMBI of -1,010.	Slight increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates. An 11% increase in the SLI, which could slightly increase sandbar building potential, and an 80% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; lower fluctuations would result in lower erosion and transport rates. A 154% increase in the SLI and a 112% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; fluctuations comparable to Alternative A. A 151% increase in the SLI and a 47% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates. A 116% increase in the SLI and a 96% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates. A 164% increase in the SLI and a 230% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates. A 173% increase in the SLI and a 182% decrease in the SMBI compared to Alternative A.
<i>Water Quality-Related Indicators</i>							
Turbidity	No change from current conditions expected.	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A
Nutrients	No change from current conditions expected.	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A

^a SLI = Sand Load Index; SMBI = Sand Mass Balance Index.

1 quality nearshore and riparian habitats (Sections 4.5, 4.6, and 4.7). Under Alternative F, the
2 timing of achieving suitable downstream main channel water temperatures could reduce overall
3 temperature suitability for spawning and incubating humpback chub and other native fishes, but
4 improve temperatures for growth of young-of-year (YOY) humpback chub (Section 4.5.2.1).
5
6

7 **4.4.3 Alternative-Specific Impacts**

8

9 Although alternatives did not differ with regard to peak and base flows, mean Glen
10 Canyon Dam release water temperature, turbidity, or nutrient concentrations, alternatives do
11 differ with regard to the magnitude and timing of HFEs, monthly flows, daily flows, within-day
12 flow fluctuations, and sediment dynamics. These factors have the potential to produce only small
13 changes in current conditions and thus are expected to have relatively small effects on natural
14 processes, as discussed below. In 2026, the Interim Guidelines for Lower Basin Shortages and
15 Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a) that are currently
16 in place will expire. Without knowing how dam operations may change at that time, it is not
17 possible to postulate with any acceptable level of certainty how natural processes may be
18 affected. Thus, the following assessments of alternative-specific impacts do not consider any
19 changes in operations after 2026.
20
21

22 **4.4.3.1 Alternative A (No Action Alternative)**

23

24 Under Alternative A, there would be little change in physical parameters from current
25 conditions; mean monthly release volumes, mean daily flows, and mean daily changes in flow
26 would be the same as current conditions (Section 4.2). Because the current HFE protocol as
27 defined in the 2011 EA (Reclamation 2011b) would continue under Alternative A, sediment
28 deposition rates would not be expected to differ from current levels. Sandbar building would be
29 expected to continue through the HFE protocol window, but bars would likely then erode and
30 decrease in size after 2020 (Section 4.3). Vegetation and wildlife dependent on replenished
31 sandbars would decline in abundance after the protocol expires in 2020 (Sections 4.6 and 4.7).
32

33 Under Alternative A, no changes from current conditions are expected in physical factors
34 associated with monthly volumes, daily flows, and flow changes, water temperature, and water
35 quality. As a consequence, natural processes in the Colorado River between Glen Canyon Dam
36 and Lake Mead are not expected to differ from current conditions.
37
38

39 **4.4.3.2 Alternative B**

40

41 Under Alternative B, mean monthly volumes and mean daily flows would be the same as
42 those under Alternative A (Sections 4.2 and 4.3), and thus natural processes influenced by these
43 parameters are not expected to change from current conditions. However, Alternative B would
44 have a greater mean daily change in flow in all months (Section 4.2), and thus may affect natural
45 processes that govern aquatic ecology and vegetation, decreasing nearshore habitat stability
46 affecting native fish, benthic productivity, and aquatic invertebrates that would otherwise inhabit

1 these areas (Section 4.5). This increase in mean daily change in flow would also favor wetland
2 processes along the river corridor below the dam and affect vegetation and wildlife species that
3 inhabit wetland habitats (e.g., marsh vegetation, wetland invertebrates, and amphibians;
4 Sections 4.6 and 4.7) along the corridor. In addition, this increase in within-day fluctuations is
5 expected to inhibit trout production somewhat relative to Alternative A and all other alternatives,
6 and could reduce competition with and predation by trout on, and result in slightly higher
7 abundance of, humpback chub and other native fish (Section 4.5). Note that experimental
8 hydropower improvement flows that would be implemented under Alternative B could result in a
9 reduction in existing wetland area and would result in lower trout production than other
10 alternatives.

11
12 While the average and maximum number of sediment-triggered HFEs would be similar to
13 that under Alternative A, the SLI (an indicator of sandbar building potential) could be higher
14 under Alternative B (Section 4.3). Thus, sediment-influenced natural processes that affect
15 riparian vegetation, terrestrial wildlife, and nearshore aquatic habitats (such as backwaters) could
16 be somewhat improved under Alternative B, but would be diminished relative to all other
17 alternatives, which have more frequent HFEs. Within-day flow fluctuations would result in
18 higher rates of sandbar erosion than under any other alternative.

19
20 In summary, in comparison to Alternative A, the higher mean daily changes in flow
21 under Alternative B in all months may act to decrease sediment conservation and favor wetland
22 processes (unless hydropower improvements are implemented), but reduce trout production and
23 nearshore habitat stability (which would affect fish, aquatic invertebrates, and benthic
24 productivity in those habitats).

25 26 27 **4.4.3.3 Alternative C**

28
29 Mean monthly volumes as well as mean daily flows under Alternative C would be higher
30 in February through May, but lower in August through October when compared to Alternative A.
31 While these differences are relatively small (Section 4.2), the reduced volume in August through
32 November would favor sediment retention during the monsoon period and increase the
33 frequency, magnitude, and duration of HFEs, the size and persistence of sandbars and associated
34 backwaters, and the vegetation and wildlife species that depend on replenished sandbars
35 (Sections 4.3, 4.6, and 4.7). The timing of spring HFEs would coincide more closely with the
36 natural timing of the annual spring peak flow and could contribute to processes dependent on a
37 spring peak flow. In addition, within-day changes in flow would be lower in all months under
38 Alternative C than under Alternatives A, B, D, and E. The lower magnitude of daily changes in
39 flows under Alternative C would reduce erosion rates of sandbars, and may improve the quality
40 and stability of some nearshore aquatic habitats (including backwaters) and benefit fish and
41 aquatic invertebrates in these areas, as well as some riparian habitats and biota (Sections 4.5, 4.6,
42 and 4.7). This decrease in daily fluctuations would favor trout production (with possible negative
43 effects on native fish that would be offset by implementation of trout management actions) and
44 inhibit maintenance of wetlands and species dependent on them (Sections 4.5, 4.6, and 4.7).

1 In summary, compared to Alternative A, the higher monthly release volumes and daily
2 flows in winter, spring, and summer, and the lower mean daily changes in all months under
3 Alternative C may increase sediment conservation and increase the stability of nearshore
4 habitats, and thus benefit biota that use those habitats, increase trout production, and reduce
5 wetland area. The higher frequency of HFEs would increase sandbar building relative to
6 Alternative A.

9 **4.4.3.4 Alternative D (Preferred Alternative)**

10
11 Compared to Alternative A, Alternative D would have slightly higher mean monthly
12 volumes and daily flows in November and February through April, and lower volumes and flows
13 in December, January, and July through September (Section 4.2), providing less seasonal
14 variation in flow across the year than most alternatives. Mean daily changes in flow for
15 Alternative D would be comparable to Alternative A. Thus natural processes influenced by daily
16 changes in flow would differ little from current conditions. Therefore, the quality and stability of
17 some nearshore aquatic habitats (including backwaters) could be comparable to those under
18 current conditions and are expected to support similar fish and aquatic invertebrates in these
19 areas. Within-day fluctuations in flow are expected to support current levels of wetland
20 vegetation or provide some increase in wetlands (Section 4.6), as well as the invertebrate and
21 wildlife species that inhabit wetlands (Section 4.7). Under Alternative D, there may be some
22 slight downstream warming, which could improve downstream main channel temperature
23 suitability for spawning and incubation of native fish.

24
25 The relatively even pattern of monthly volumes would serve to conserve sand, and, as a
26 consequence, spring and fall HFEs would be triggered frequently under Alternative D. Thus, this
27 alternative has a relatively high potential for bar building compared to other alternatives
28 (Section 4.3). The higher number of HFEs could influence sediment-related natural processes
29 that would build and maintain backwaters (Section 4.5) and support the vegetation and wildlife
30 species that depend on replenished sandbars (Sections 4.6 and 4.7).

31
32 In summary, natural processes influenced by monthly volumes, daily flows, and within-
33 day changes in flow would differ little between Alternatives A and D. However, the more even
34 monthly release volumes and daily flows would favor sediment conservation and also provide
35 some increase in downstream temperature suitability for spawning and incubation of native fish
36 in spring, while nearshore aquatic habitat stability would be similar to that under Alternative A.
37 The higher frequency of HFEs would increase sandbar building relative to Alternative A.

38 39 **4.4.3.5 Alternative E**

40
41
42 Compared to Alternative A, mean monthly volumes as well as mean daily flows would
43 be higher in October, November, and February through March, but lower in December, January,
44 July, August, and September. August and September volumes would be lower to conserve
45 sediment during the monsoon period. Mean daily changes in flow under Alternative E would be
46 higher than under Alternative A in all months but September and October, when daily changes

1 would be lower. The greater daily changes in flow under this alternative could increase the
2 erosion rates of sandbars and act to reduce the quality and stability of nearshore aquatic and
3 riparian habitats (Sections 4.5, 4.6, and 4.7). This increase in within-day fluctuations also is
4 expected to inhibit nonnative trout production somewhat relative to Alternative A and all other
5 alternatives but Alternative B, and could result in reduced competition with and predation by
6 trout on humpback chub and other native fish (Section 4.5).

7
8 Alternative E would have more sediment-triggered HFEs than Alternatives A and B, but
9 slightly fewer than the other alternatives (Section 4.3), and, therefore, a greater potential for
10 sediment conservation and deposition, and significantly more potential for bar building, than do
11 Alternatives A or B. The lower August through October volumes are intended to conserve sand
12 input during the monsoon period and would result in an increase in the frequency, magnitude,
13 and duration of sediment-triggered HFEs, which would influence sediment-related natural
14 processes that would build and maintain backwaters (Section 4.5) and support the vegetation and
15 wildlife species that depend on replenished sandbars (Sections 4.6 and 4.7).

16
17 In summary, in comparison to Alternative A, the relatively even monthly release volumes
18 and daily flows of Alternative E, together with lower summer volumes and flows, may favor
19 sediment conservation during monsoon periods, while higher mean daily changes in flow in all
20 months but October and November may reduce nearshore habitat stability, reduce trout
21 production, and increase wetland area.

22 23 24 **4.4.3.6 Alternative F**

25
26 In contrast to all other alternatives, Alternative F has a pattern of monthly volumes and
27 daily flows that are seasonally adjusted to more closely match the pattern of Lake Powell inflow,
28 with high spring flows and low summer through winter flows. Under Alternative F, the highest
29 mean monthly release volumes and mean daily flows occur in March through June, and lower
30 volumes and daily flows occur in December, January, and July through August (Section 4.2).
31 Under Alternative F, there would be no within-day flow changes except those needed for HFEs
32 or other high-flow releases, or as a result of changes in the runoff forecast, equalization flows, or
33 natural precipitation events and tributary inflows. Thus among all the alternatives, Alternative F
34 is expected to result in flow-related natural processes that are most different from current
35 conditions. Steady flows are expected to reduce the erosion of sandbars, provide for more stable
36 main channel and nearshore aquatic habitats, and increase productivity in these habitats
37 (Sections 4.5, 4.6, and 4.7), but would also result in decreases in wetland habitat and the species
38 dependent on those habitats, as well as favor trout production with potential adverse effects on
39 native fish. Unlike Alternatives B, C, D, E, and G, Alternative F would not include
40 implementation of trout management actions.

41
42 Relative to other alternatives, Alternative F would have the least amount of downstream
43 warming, and thus the coolest downstream main channel water temperatures in spring and the
44 greatest amount of downstream warming and warmest downstream temperatures in summer
45 (Section 4.2). This pattern and magnitude of downstream warming are due, in part, to the
46 monthly patterns in release volumes and daily flows, as well as the relative absence of daily flow

1 fluctuations, under Alternative F. As a result, temperature-linked natural processes could be
2 affected more under Alternative F than under any of the other alternatives. For example,
3 temperature suitability for trout may decrease at downstream locations but increase downstream
4 for other nonnative fish (Section 4.5). Alternative F would have the greatest reduction in
5 temperature suitability for spawning and incubating at humpback chub aggregation areas, while
6 temperature suitability for humpback chub growth in the main channel would be greatest under
7 this alternative.
8

9 Alternative F has a greater potential for sediment conservation and deposition, and
10 significantly more potential for bar building, than for all alternatives but Alternative G, but the
11 lowest SMBI. These HFEs would influence sediment-related natural processes that would build
12 and maintain backwaters (Section 4.5) and support the vegetation and wildlife species that
13 depend on replenished sandbars (Sections 4.6 and 4.7).
14

15 In summary, the monthly release volumes and daily flows under Alternative F would
16 more closely match the pattern of inflows, with high spring and low summer through winter
17 flows. In comparison with Alternative A, this pattern of monthly volumes and daily flows,
18 together with steady within-day flows, would increase sediment conservation, increase nearshore
19 habitat stability, increase trout production, and reduce wetland area. The greatest amount of
20 winter, summer, and fall warming, and least amount of spring warming, of all alternatives may
21 lower temperature suitability for spawning and incubation in the spring for native fish, but
22 increase the suitability in summer and fall for growth.
23
24

25 **4.4.3.7 Alternative G**

26
27 Under Alternative G, mean monthly volumes as well as mean daily flows would be
28 higher in October, November, and February through April, but lower in December, January,
29 July, and August (Section 4.2). These steady flows would serve to conserve sediment relative to
30 other alternatives but would provide no seasonal variability, and therefore could affect natural
31 processes reliant on such variability. There would be no mean daily changes in flow except for
32 ramping during HFEs or in response to changes in the runoff forecast, equalization flows, or
33 precipitation events and tributary inflows. Steady flows are expected to reduce the erosion of
34 sandbars, improve the quality and stability of nearshore and main channel aquatic habitats, and
35 increase benthic productivity (Section 4.5). However, reduced fluctuations would also result in a
36 decrease in wetland habitat and the species dependent on those habitats (Section 4.6), as well as
37 favor trout production with potential adverse effects on native fish (Section 4.5). Increases in
38 trout production would be offset by trout management actions.
39

40 Alternative G would have less downstream warming, and thus cooler downstream main
41 channel water temperatures in spring and warmer downstream temperatures in summer,
42 compared to Alternative A and all other alternatives but Alternative F (Section 4.2). As with
43 Alternative F, this pattern of downstream warming is due, in part, to the pattern of monthly
44 release volumes under Alternative G.
45

1 Alternative G has the highest average number of sediment-triggered HFEs of all the
2 alternatives (Section 4.3). Alternative G is also the only alternative that would allow for
3 durations of up to 336 hr at the 45,000-cfs peak flow, with no limit to the number of such flows.
4 These HFEs would result in the most bar-building of any of the alternatives, and thus influence
5 sediment-related natural processes that would build and maintain backwaters (Section 4.5) and
6 support the vegetation and wildlife species that depend on replenished sandbars (Sections 4.6
7 and 4.7). The SMBI was the second lowest for this alternative.
8

9 In summary, the more even monthly release volumes and daily flows under
10 Alternative G, together with steady within-day flows, may increase sediment conservation,
11 increase nearshore habitat stability, increase trout production, and decrease wetland area. This
12 alternative also has the second-highest summer warming of all alternatives, which may increase
13 temperature suitability for growth of native fish in summer.
14

15 16 **4.5 AQUATIC ECOLOGY**

17
18 The assessment of impacts on aquatic
19 ecology focused on four groups of aquatic
20 resources: the food base (consisting of
21 invertebrates, algae, and aquatic plants), native
22 fish (including the endangered humpback chub
23 [*Gila cypha*]), nonnative fish (including rainbow
24 trout [*Oncorhynchus mykiss*]), and aquatic fish
25 parasites. The specific attributes and conditions
26 evaluated, the analysis methods, and the
27 assessment results are presented in the following
28 sections. Additional details are provided in
29 Appendix F.
30

31 32 **4.5.1 Analysis Methods**

33
34 The evaluation of the potential impacts of LTEMP alternatives on aquatic resources
35 below Glen Canyon Dam is based on alternative-specific differences in operations (including
36 monthly and annual flow patterns and within-day flow fluctuations), and flow and non-flow
37 actions. These characteristics of alternatives can affect aquatic organisms directly or through
38 their effects on habitat availability and quality. The analysis methods for impacts on aquatic food
39 base, native fish, nonnative fish, and aquatic parasites are presented next.
40

41 42 **4.5.1.1 Aquatic Food Base**

43
44 The aquatic food base assessment considers the effects of flow and temperature on the
45 amount of food that is available to fish and other animals in Glen and Grand Canyon. The
46 assessment focuses on changes at key locations in the Colorado River: RM 0 (Lees Ferry within

Issue: How do alternatives affect aquatic resources (food base, native and nonnative fishes, and fish parasites) between Glen Canyon Dam and Lake Mead?

Impact Indicators:

- Abundance, distribution, and availability of the aquatic food base
- Native and nonnative fish reproduction, survival, growth, and distribution
- Availability and quality of aquatic habitats
- Distribution and potential for spread of fish parasites

1 the Glen Canyon reach), RM 61 (Little Colorado River within the Marble Canyon reach), and
2 RM 225 (Diamond Creek within the Grand Canyon reach). As discussed in Section 3.2.1.2,
3 within-day flow variation in releases continues downstream and decreases little as flows pass
4 through Marble and Grand Canyons. Water, on the other hand, can warm considerably by the
5 time it travels from the dam to western Grand Canyon (Section 3.2.2.2).

6
7 The effects of flow and temperature on the aquatic food base were evaluated by
8 examining a number of important factors. The potential influence of flow on the aquatic food
9 base includes changes in invertebrate drift (food organisms dislodged and moved by river
10 current, e.g., algae, plankton, invertebrates, and larval fish); stranding of aquatic organisms in the
11 varial zone (the portion of the river's edge affected by the daily range of flows); and effects to
12 species abundance, composition, and diversity. Stranding of organisms in the varial zone may
13 lead to their death, while growth of primary producers such as *Cladophora* is reduced in the
14 varial zone. The potential influence of temperature includes changes in diatom composition;
15 invertebrate egg development, fecundity, growth, maturation, number of yearly generations,
16 and/or emergence of adults for aquatic insects with terrestrial adult stages; invertebrate
17 composition, diversity, and production (e.g., biomass of benthic macroinvertebrates per unit of
18 area per unit of time); and occurrence and distribution of invasive and parasitic species
19 (Clarke et al. 2008; Poff et al. 1997; Power et al. 1988; Renöfält et al. 2010).

20
21 To assess potential flow effects on the aquatic food base, a qualitative comparison among
22 alternatives was conducted because an appropriate quantitative model was not available. This
23 qualitative analysis was based on potential impacts of elements of base operations (e.g., release
24 volumes, maximum and minimum flows, daily flow range, and ramp rates) and other
25 experimental flow actions (e.g., HFEs, low summer flows, TMFs, and hydropower improvement
26 flows). To assess potential temperature effects on the aquatic food base, expected mean monthly
27 temperatures at Lees Ferry, Little Colorado River, and Diamond Creek were compared to
28 temperature requirements for select primary producers, zooplankton, and benthic
29 macroinvertebrate species (Valdez and Speas 2007).

30 31 32 **4.5.1.2 Nonnative Fish**

33
34 The assessment of impacts on nonnative fish evaluated effects on reproduction, survival,
35 growth, and abundance downstream of Glen Canyon Dam. The assessment considered results of
36 previous investigations conducted below Glen Canyon Dam that examined the status and
37 abundance of nonnative fish (e.g., see Makinster et al. 2010), as well as studies of the effects of
38 experimental flows (such as HFEs and trout removal flows) on nonnative fish
39 (e.g., Makinster et al. 2011; Korman et al. 2012). In addition, species-specific models that
40 incorporated factors such as annual release volumes, water temperatures, and monthly and
41 within-day changes in flows were used to examine effects at selected locations downstream of
42 Glen Canyon Dam.

43
44 A coupled rainbow trout–humpback chub model was used to evaluate potential effects of
45 alternatives on (1) the number and size of rainbow trout in the Glen Canyon reach, and (2) the
46 number of age-0 rainbow trout expected to move (emigrate) into the Marble Canyon and Little

1 Colorado River reaches over the 20-year LTEMP period. The model estimates the number of
2 rainbow trout that move downstream as a function of trout spawning and recruitment in the Glen
3 Canyon reach. Historic observations and previous modeling suggest that recruitment of rainbow
4 trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in
5 years with HFEs (especially spring HFEs), and in years with lower levels of within-day
6 fluctuations (Korman, Kaplinski et al. 2011; Korman, Persons et al. 2011; Korman et al. 2012;
7 Section 3.5.4). The number of trout recruits in the Glen Canyon reach, and the numbers of trout
8 and humpback chub in the Little Colorado River reach were used to determine when TMFs and
9 mechanical removal in the Little Colorado River reach, respectively, would be triggered under
10 certain alternatives.

11
12 Technical details about the coupled rainbow trout-humpback chub model are presented in
13 Appendix F. The combined model uses an age-structured population dynamics model to predict
14 the abundance and growth of rainbow trout in Glen Canyon, and the number of those fish that
15 migrate into Marble Canyon. The model makes predictions on an annual time step for fish that
16 are 1 to 6 years of age. Annual recruitment (i.e., the number of age-0 fish that enter the
17 population in a given year) is predicted based on flow statistics, and annual growth is predicted
18 as a decreasing function of overall rainbow trout abundance. Abundance, in combination with
19 estimates of age-specific angling vulnerabilities, is used to make predictions of angling catch
20 rates and predicted abundance and size distributions are used to compute the number of quality-
21 sized fish (i.e., trout ≥ 16 in. total length) potentially available for capture in the fishery. The
22 number of fish migrating into Marble Canyon each year (out-migrants) is predicted as a
23 proportion of the previous year's recruitment, and is used as an input in a submodel that
24 estimates the potential number of fish that eventually migrate down to the confluence of the
25 Little Colorado River, where their effects on humpback chub are simulated in the humpback
26 chub submodel. Basic parameters and those for key functional relationships in the trout
27 submodel were derived or fitted to values from a stock synthesis model developed by
28 Korman et al. (2012). That model used 21 years of electrofishing-based catch-per-effort data for
29 Glen and Marble Canyons, in conjunction with length frequencies and considerable auxiliary
30 information, to estimate annual recruitment, survival rate, growth parameters, and outmigration
31 patterns for rainbow trout.

32
33 As with most models of biological systems, a number of simplifications and assumptions
34 were made in the rainbow trout-humpback chub model. The model was tested by comparing
35 predictions of key state variables such as recruitment, outmigration, and size at the terminal age
36 generated using flow statistics from the historical record between 1990 and 2010 with
37 observations and best estimates of those values for the same period. Predictions of angling catch
38 rates were compared to annual estimates derived from creel surveys (Makinster et al. 2011).
39 Predictions of rainbow trout abundance were compared to interannual trends from electrofishing
40 surveys conducted by the AZGFD. Predictions of recruitment, asymptotic length, and
41 outmigration were compared to best-fit estimates from a stock synthesis model developed by
42 Korman et al. (2012). Overall, the predictions generated by the model resulted in a relatively
43 good fit to historic observations and estimates.

44
45 Water temperature is a major factor affecting the distribution and abundance of fish
46 through effects on reproduction, growth, and survival (Valdez and Speas 2007). A temperature

1 model (Wright, Anderson et al. 2008) was used to estimate alternative-specific downstream
2 temperatures and determine their suitability to support reproduction, growth, and survival of
3 nonnative fish (specifically, rainbow and brown trout, smallmouth bass, green sunfish, channel
4 catfish, and striped bass) at locations downstream of Glen Canyon Dam. The temperature
5 suitability model assumed that the potential for self-sustaining populations of nonnative fish at
6 specific locations is related to the combined suitability of temperatures for spawning, egg
7 incubation, and growth of each species. Possible values for temperature suitability can
8 theoretically range from 0 (completely unsuitable for one or more life history aspects) to 1
9 (magnitude and timing of temperatures would be optimal for all life history aspects). The
10 temperature suitability modeling evaluates the potential for all life history needs to be met in the
11 mainstem river, but some species are known to use tributaries for spawning, incubation, and
12 growth. Thus, the model predicts relatively low temperature suitability even in some areas where
13 species populations appear to be self-sustaining. In addition, modeled temperatures do not
14 consider the potential for warming near tributary mouths or in shallow nearshore areas. Thus, the
15 results of temperature suitability modeling should be used to compare relative effects of
16 alternatives on species-specific temperature needs in the mainstem Colorado River, rather than as
17 an exact predictor of the potential for the presence or absence of nonnative fish species at
18 particular locations.

19

20 The distribution and abundance of nonnative fish also can be influenced by the effects of
21 flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal
22 ponding of tributary mouths, sediment transport and deposition, and food base characteristics
23 (Section 3.5.3). Alternative-specific flows were evaluated to assess their effects on these
24 parameters.

25

26

27 **4.5.1.3 Native Fish**

28

29 The assessment of impacts on native fish considered the effects of alternative-specific
30 differences in mainstem flow, water temperature, and sediment regimes on the following:

31

- 32 • The potential for the establishment of self-sustaining populations of native
33 fish at selected mainstem locations;
- 34 • Changes in potential levels of competition and predation from nonnative fish;
- 35 • Potential increases in parasite infestations; and
- 36 • Main channel and nearshore habitat quality, quantity, and stability.

37

38

39 The evaluation of potential impacts of the alternatives on native fish included
40 consideration of the results of previous investigations conducted below Glen Canyon Dam that
41 examined the status and abundance of native fish (e.g., Coggins and Walters 2009;
42 Albrecht et al. 2014; Gerig et al. 2014), as well as studies of the effects of experimental flows
43 (such as HFEs and other flows) and water temperature on native fish (e.g., Makinster et al. 2011;
44 Korman et al. 2010; Ward 2011; Ward and Morton-Starnier 2015).

45

1 The coupled rainbow trout–humpback chub model described in Section 4.1.2.2 also was
2 used to evaluate potential effects of alternatives on the humpback chub population in the Little
3 Colorado River aggregation over the 20-year LTEMP period. The model estimated survival,
4 growth, and abundance of adult humpback chub based on water temperatures and the estimated
5 abundance of rainbow trout in the Little Colorado River reach, as well as previously reported
6 rates (Yackulic et al. 2014). The effects of triggered mechanical removal and TMFs on trout
7 abundance also were modeled. In order to evaluate the potential for operational scenarios to lead
8 to extinction or improvement of the humpback chub population in the Grand Canyon, the
9 modeled estimate of the minimum number of adult humpback chub that would occur during each
10 20-year simulation period was compared among alternatives.

11
12 Technical details about the humpback chub submodel are provided in Appendix F. The
13 humpback chub submodel was based on the best available scientific information. As presented in
14 Appendix F, the model provided a good fit between simulated adult humpback abundance and
15 abundance estimates developed by Coggins and Walters (2009) for a period of time (1990–2008)
16 that is separate from the period of time (2009–2013) over which most parameters were
17 estimated. However, like all models, it is a simplified representation of the actual system it seeks
18 to describe.

19
20 Water temperature is an important factor that affects the distribution and abundance of
21 native fish through its effects on reproduction, growth, and survival (Valdez and Speas 2007).
22 Species-specific models were used to estimate temperature suitability for native fish (including
23 humpback chub) using the same methods and assumptions described in Section 4.5.1.2. As
24 mentioned in that section, the results of temperature suitability modeling should be used to
25 compare relative effects of alternatives on species-specific temperature needs in the mainstem
26 Colorado River, rather than an exact predictor of the potential for the presence or absence of
27 native fish species at particular locations.

28
29 The distribution and abundance of native fish also can be influenced by the effects of
30 flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal
31 ponding of tributary mouths, sediment transport and deposition, turbidity (which may affect
32 predation rates), and food base characteristics (Section 3.5.3). Alternative-specific flows were
33 evaluated to assess their effects on these parameters.

34 35 36 **4.5.1.4 Aquatic Parasites**

37
38 The potential for fish parasites to expand their distribution within the river and result in
39 infestations of native and nonnative species was examined for each alternative. Species-specific
40 temperature suitability models, together with information on current distribution, life history, and
41 ecological requirements (e.g., McKinney, Robinson et al. 2001; Choudhury et al. 2004;
42 Hoffnagle et al. 2006) were used to predict the potential for each alternative to provide
43 conditions in the mainstem river that could increase the occurrence and abundance of fish
44 parasites at selected locations between Glen Canyon Dam and Lake Mead. The evaluations
45 focused on four parasite species: Asian tapeworm (*Bothriocephalus acheilognathi*), anchor worm
46 (*Lernaea cyprinacea*), trout nematode (*Truttaedacnitis truttae*), and whirling disease (*Myxobolus*
47 *cerebralis*).

1 **4.5.2 Summary of Impacts**
2

3 The potential impacts of each alternative on the aquatic food base, trout, warmwater
4 nonnative fish, native fish, and aquatic parasites are summarized in Table 4.5-1 and described in
5 the following sections.
6

7
8 **4.5.2.1 Aquatic Food Base**
9

10 The impacts of LTEMP alternatives on the aquatic food base are expected to be
11 negligible, beneficial, or adverse depending on the alternative. Some operational characteristics
12 may cause both beneficial and adverse impacts (e.g., benthic productivity may increase while
13 drift rates decrease with a reduction in daily fluctuations). The impacts are described in the
14 following sections.
15

16
17 **Flow Effects on the Aquatic Food Base**
18

19 In general, flow effects on the aquatic food base depend on the magnitude of daily flows
20 and the within-day and seasonal variability of those flows. The low-flow channel (permanently
21 wetted area) supports most of the primary and secondary production in regulated rivers
22 (Jones 2013b). Steady flows or reduced fluctuations may create conditions that allow a large
23 standing crop of benthic algae and invertebrates to develop, particularly during spring and
24 summer months (Leibfried and Blinn 1987; Pinney 1991; Shannon et al. 2001). Steady flows
25 may also prevent the daily loss or reduction in size of backwaters. More stable backwaters
26 potentially support increased planktonic and benthic communities (Reclamation 1995;
27 Behn et al. 2010). Steady flows or reduced fluctuations may increase benthic productivity over
28 the long term, and this will increase invertebrate drift (the preferred food of fish such as trout that
29 feed in the water column) over the long term (Kennedy, Yackulic et al. 2014).
30

31 Flows up to 31,500 cfs do not have a large scouring effect on the aquatic food base
32 downstream of Glen Canyon Dam, whereas flows of 41,000 to 45,000 cfs may scour a large
33 portion of the aquatic food base (Reclamation 2011b). The highest mean daily flows for most
34 alternatives would be <14,700 cfs (in an 8.23-maf year), except under Alternative F, which
35 would have mean daily flows of 20,000 cfs in May and June. Thus, aquatic food base scouring
36 would not be expected from base operations regardless of alternative. All alternatives would
37 have HFEs of 45,000 cfs that would last up to 96 hr, while the lengthiest 45,000 cfs HFEs would
38 be 250 hr for Alternative D and 336 hr for Alternative G. Scouring of the aquatic food base by
39 HFEs would be expected for all alternatives. The potential extent of benthic scouring, and the
40 subsequent length of time needed for recovery of the aquatic food base, would be higher with
41 longer duration 45,000 cfs HFEs. Also, the number of HFEs would affect scouring and
42 subsequent recovery of the aquatic food base. Table 4.5-2 summarizes the impact on the aquatic
43 food base from HFEs from Glen Canyon Dam that occurred between 1996 and 2008.
44

45 The seasonal timing of HFEs (i.e., spring vs. fall) may influence the magnitude of
46 ecological response and recovery rates of ecosystem processes. Recovery times are generally

1 **TABLE 4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology**

Aquatic Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows, compared to Alternative A. Habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced compared to Alternative A. Lower trout abundance and slightly higher humpback chub abundance than Alternative A.	Slightly higher productivity of benthic aquatic food base and drift, compared to Alternative A. Habitat quality and stability for nonnative and native fish may be higher than under Alternative A. Higher trout abundance even with implementation of TMFs and mechanical removal, but no difference in humpback chub abundance compared to Alternative A.	Slightly higher productivity of benthic aquatic food base and drift, compared to Alternative A. Experimental steady weekend flows may further increase productivity and diversity. Habitat quality and stability for nonnative and native fish are expected to be slightly higher than under Alternative A. Negligible change in trout abundance with implementation of TMFs, and mechanical removal, and slight increase in humpback chub abundance compared to Alternative A.	Slightly higher productivity of benthic aquatic food base, and similar or increased drift, compared to Alternative A. Habitat quality and stability for nonnative and native fish would be slightly lower than under Alternative A. Lower trout abundance with implementation of TMFs and mechanical removal, and slightly higher humpback chub abundance than Alternative A	Increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year compared to Alternative A. 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 and slightly lower humpback chub abundance than Alternative A.	Productivity of aquatic food base and long-term drift relatively high compared to Alternative A. Habitat stability for nonnative and native fish would be greater than under any of the other alternatives. Higher trout abundance even with implementation of TMFs and mechanical removal, and slightly lower humpback chub abundance than Alternative A.

4-103

2

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Aquatic Food Base</i>							
Mainstem benthic productivity	No change from current conditions and levels through 2020; no HFEs after 2020 may lower blackfly and midge production.	Slightly lower productivity compared to Alternative A due to higher daily flow fluctuations; infrequent HFEs may lower conditions favorable to blackfly and midge production.	Potential increase in productivity compared to Alternative A due to more uniform monthly flows from December through August, lower daily range in flows, and more frequent HFEs (which will favor blackfly and midge production).	Potential increase in productivity compared to Alternative A due to more uniform monthly flows and more frequent HFEs (which will favor blackfly and midge production); experimental steady weekend flows may also increase productivity and diversity.	Potential increase in productivity compared to Alternative A due to more uniform monthly flows and more frequent HFEs (which favor blackfly and midge production), but increase would be offset by higher within-day flow fluctuations.	Potential increase in productivity compared to Alternative A in spring and early summer from increased monthly flows with no daily flow fluctuations, but lower rest of year due to low steady flows; frequent HFEs will favor blackfly and midge production.	Productivity relatively high compared to Alternative A and consistent throughout the year due to relatively stable monthly flows with no daily flow fluctuations, but this may favor species that lack a terrestrial adult stage; frequent HFEs will favor blackfly and midge production.
Drift	No change from current conditions and levels, although infrequent HFEs will result in short-term drift increases.	Greater fluctuations in daily flows may increase drift compared to Alternative A. Infrequent HFEs will result in short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.; Higher weekday flows following experimental steady weekend flows may temporarily increase drift.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Aquatic Food Base (Cont.)</i>							
Nearshore benthic productivity	No change from current conditions and levels, although no HFES after 2020 may adversely affect backwater establishment.	Potentially lower nearshore productivity due to higher daily range in flow compared to Alternative A; infrequent HFES throughout the LTEMP period may slightly improve backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A from lower daily flow fluctuations; more frequent HFES may favor backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A based on more uniform monthly release volumes; more frequent HFES may favor backwater establishment and maintenance.	Nearshore productivity slightly lower than Alternative A based on somewhat higher daily flow fluctuations; more frequent HFES may favor backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A from no daily flow fluctuations; more frequent HFES may favor backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A from no daily flow fluctuations; more frequent HFES may favor backwater establishment and maintenance.
<i>Trout</i>							
Spawning habitat	No change from current conditions.	Potential decrease in spawning habitat availability and stability compared to Alternative A due to higher within-day flow fluctuations during the spawning period.	Potential increase in spawning habitat availability and stability compared to Alternative A due to lower within-day flow fluctuations during the spawning period.	Slight potential decrease in spawning habitat availability and stability compared to Alternative A due to slightly greater within-day flow fluctuations during the spawning period.	Lowest spawning habitat availability and stability among all alternatives due to highest average within-day flow fluctuations during the spawning period.	Spawning habitat relatively available and stable within spring months due to absence of within-day flow fluctuations, but high flows in May and June affect availability and stability.	Greatest spawning habitat availability and stability among all alternatives due to absence of within-day flow fluctuations and even monthly distribution of flows.
Stranding	No change from current conditions and levels.	Greatest potential for increased stranding resulting from highest down-ramp rate of all alternatives	Potential increase compared to Alternative A due to higher down-ramp rate.	Similar to Alternative C.	Similar to Alternative C.	Relatively low potential for stranding compared to Alternative A due to absence of within-day flow fluctuations, but large drops in flow would occur after high flows in May and June.	Lowest potential for stranding due to absence of within-day flow fluctuations and even monthly distribution of flows.

4-105

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Trout (Cont.)</i>							
Population size in Glen Canyon reach	No change from current conditions and levels. Estimated mean abundance 95,000 age-1 and older fish.	Small potential decrease compared to Alternative A. Estimated abundance 74,000 age-1 and older fish.	Small potential increase compared to Alternative A because of frequent HFEs and lower daily flow fluctuations. Estimated mean abundance 102,000 age-1 and older fish.	Negligible change from current condition. Estimated mean abundance 93,000 age-1 and older fish.	Small potential decrease compared to Alternative A because of higher flow fluctuations. Estimated mean abundance 88,000 age-1 and older fish.	Greatest potential increase compared to Alternative A among all alternatives because of frequent HFEs and steady flows. Estimated mean abundance 160,000 age-1 and older fish.	Similar to Alternative F. Estimated mean abundance 132,000 age-1 and older fish.
Number of fish >16 in. total length (TL) in Glen Canyon reach	No change from current condition. Estimated abundance 770 fish.	Potential increase compared to Alternative A because higher fluctuations and relatively few HFEs lower recruitment and reduces competition. Estimated mean abundance 870 fish.	Negligible change from current condition. Frequent HFEs and lower fluctuations increase recruitment but TMFs control trout numbers. Estimated mean abundance 750 fish.	Negligible change from current condition. Frequent HFEs increase recruitment but TMFs control trout numbers. Estimated mean abundance 810 fish.	Potential increase compared to Alternative A because of higher fluctuations, few spring HFEs, and implementation of TMFs lower recruitment and reduces competition. Estimated mean abundance 830 fish.	Greatest potential decrease of all alternatives because steady flows, annual spring HFEs, and no TMFs result in high recruitment and increased competition. Estimated mean abundance about 600 fish.	Potential decrease. compared to Alternative A. Steady flows and frequent HFEs result in high recruitment and increased competition, but TMFs offset increases. Estimated mean abundance about 700 fish.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Trout (Cont.)							
Emigration from Glen Canyon to Marble Canyon	No change from current conditions. Estimated mean emigration about 37,000 fish/yr.	Lowest potential emigration of all alternatives because higher fluctuations and relatively few HFEs lower recruitment. Estimated mean emigration about 30,000 fish/yr.	Potential increase in emigration compared to Alternative A. Frequent HFEs and lower fluctuations increase recruitment. Estimated mean emigration about 44,000 fish/yr.	Potential increase in emigration. Frequent HFEs increase recruitment, but offset by fluctuations and TMFs. Estimated mean emigration about 41,000 fish/yr.	Negligible change from current conditions; fewer spring HFEs, higher fluctuations, and TMFs result in low recruitment. Estimated mean emigration about 38,000 fish/yr.	Highest potential emigration of all alternatives. Annual spring HFEs, steady flows, and lack of TMFs result in high recruitment. Estimated mean emigration about 72,000 fish/yr.	Potential increase in emigration compared to Alternative A. Steady flows and frequent HFEs result in high recruitment, but TMFs offset increases. Estimated mean emigration about 59,000 fish/yr.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Some improvement in suitability at RM 61 but reduced suitability at RM 157 and RM 225.	Similar to Alternative A.
Warmwater Nonnative Fish							
Nearshore habitat quality, availability, and stability	No change from current levels and conditions.	Possible decrease compared to Alternative A due to highest ramp rates and within-day flow fluctuations of all alternatives.	Potential increase compared to Alternative A associated with lower within-day fluctuations.	Potential increase in habitat availability and stability compared to Alternative A based on more uniform monthly release volumes.	Possible decrease compared to Alternative A due to higher within-day fluctuations in most months.	Possible increase compared to Alternative A resulting from elimination of within-day flow fluctuations.	Similar to Alternative F.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.

4-107

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Aquatic Parasites</i>							
Potential for increased establishment and infestation	No change from current conditions and levels.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.
<i>Native Fish</i>							
Humpback chub population size	No change from current levels. Estimated average minimum number of adults about 5,000; estimated lowest minimum number of adults about 1,500.	Greatest potential increase compared to Alternative A resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,400; estimated lowest minimum number of adults about 1,900.	Negligible change from current levels. Estimated average minimum number of adults 5,000; estimated lowest minimum number of adults about 1,500.	Potential increase. compared to Alternative A resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,200; estimated lowest minimum number of adults about 1,800.	Potential increase. compared to Alternative A resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,300; estimated lowest minimum number of adults about 1,600.	Greatest potential decrease of all alternatives resulting from highest increases in trout recruitment. Estimated average minimum number of adults about 4,400; estimated lowest minimum number of adults about 1,400.	Potential decrease. compared to Alternative A resulting from increased trout recruitment. Estimated average minimum number of adults about 4,700; estimated lowest minimum number of adults about 1,700.
Temperature suitability for humpback chub at aggregation locations	No change from current levels at all locations.	Similar to Alternative A.	Small potential reduction compared to Alternative A.	Similar to Alternative A.	Small potential reduction compared to Alternative A.	Greatest potential reduction compared to Alternative A.	Similar to Alternative A.
Humpback chub growth in main channel	Negligible change from current conditions. Estimated growth of YOY humpback chub in mainstem about 24 mm at RM 61 and about 50 mm at RM 213.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Greatest potential increase of all alternatives. Estimated growth of YOY humpback in mainstem about 26 mm at RM 61 and about 54 mm at RM 213.	Similar to Alternative A.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Native Fish (Cont.)</i>							
Temperature suitability for other native fish	Negligible change from current levels at all locations.	Similar to Alternative A.	Similar to Alternative A.	Small potential increase at downstream locations compared to Alternative A.	Similar to Alternative A.	Small decrease at RM 225 compared to Alternative A.	Slight potential increase at downstream locations compared to Alternative A.
Interactions between native and nonnative fish	Negligible change from current levels for most species	Negligible change compared to Alternative A for most species. Possible decrease in humpback chub–rainbow trout interactions with reduced trout emigration to Marble Canyon reach.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative B.	Possible increase in interactions with warmwater nonnative fish at downstream locations compared to Alternative A, highest rainbow trout emigration to Marble Canyon among all alternatives may adversely affect humpback chub.	Similar to Alternative F.

1 **TABLE 4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic Food**
 2 **Base**

High Flow Event	Impact on Aquatic Food Base
45,000 cfs for 7 days, March 26–April 2, 1996	Scouring; 3 to 4 month reduction in abundance and biomass
31,000 cfs for 3 days, November 5–7, 1997	No effects detected
31,000 cfs for 3 days, May 2–4, 2000	No effects detected
31,000 cfs for 3 days, September 4–6, 2000	Some taxa and reaches affected; recovery period not determined
41,000 cfs for 2.5 days, November 21–23, 2004	Possible delayed recovery because HFE occurred in the fall after the growing season
41,500 cfs for 2.5 days, March 5–7, 2008	Reduced biomass of some taxa (e.g., New Zealand mudsnails and <i>Gammarus</i>) persisted for >1 year; enhanced drift biomass of some taxa such as midges and blackflies associated with their increased benthic production that lasted >1 year

Source: Reclamation (2011b); Cross et al. (2011).

3
 4
 5 shorter for spring HFEs than for fall HFEs as a result of longer day lengths and warmer river
 6 temperatures in spring and summer. Fall HFEs precede winter months of minimal insolation, low
 7 temperatures, and reduced gross primary productivity (Cross et al. 2011). Controlled floods are
 8 expected to favor production of midges and blackflies within the Glen Canyon Dam tailwaters,
 9 apparently because the short-term adverse effects of scouring lead to an increase in future habitat
 10 quality for these organisms (Cross et al. 2011). In addition, although an HFE could reduce total
 11 invertebrate production, it may increase the amount of invertebrate prey available to rainbow
 12 trout by shifting the invertebrate assemblage toward species that are prone to drift
 13 (Cross et al. 2011). Fewer HFEs would occur under Alternatives A and B (Table 4.2-1).
 14 Therefore, these alternatives are not expected to cause long-term changes in invertebrate
 15 production due to HFEs, but neither would they favor the production of midges and blackflies in
 16 the short term after the HFE. The other five alternatives would have HFEs frequent enough to
 17 alter mainstem benthic productivity, which favors blackfly and midge production (Table 4.5-1).

18
 19 Understanding the cumulative effects of multiple HFEs will be an important
 20 consideration of the experimental plan for all alternatives except Alternatives A and B (because
 21 these alternatives have relatively few HFEs during the 20-year LTEMP period). More frequent
 22 HFEs in the Grand Canyon could cause a shift to more scour-resistant taxa, resulting in an
 23 overall decrease in macroinvertebrate diversity, and possibly abundance, resulting in a reduction
 24 in the aquatic food base (Reclamation 2011a). Section F.2.2.1 (Appendix F) has a more thorough
 25 discussion of potential effects on the aquatic food base associated with more frequent HFEs.

26
 27 During TMFs, drift rates should increase under the greater range of daily flow variations.
 28 No TMFs would occur under Alternative F, and TMFs would be tested under Alternative A (No

1 Action Alternative). TMFs would be tested and implemented, if tests are successful, for the other
2 alternatives.

3
4 A more thorough discussion of potential flow effects on the aquatic food base is provided
5 in Appendix F.

8 **Temperature Effects on the Aquatic Food Base**

9
10 The species composition, diversity, and production of the aquatic food base in the
11 Colorado River could change in response to water temperature variations (Stevens,
12 Shannon et al. 1997; Valdez et al. 2000). Blinn et al. (1989) observed that epiphytic diatom
13 communities, which serve as an important food source for macroinvertebrates and some fish,
14 change from upright (stalked) diatoms to closely adnate diatoms (those that grow flat on the
15 substrate) with an increase in water temperature from 12 to 18°C (54 to 64°F). This is an
16 important consideration because adnate forms of diatoms are generally more difficult for
17 macroinvertebrates and fish to consume compared to stalked diatoms.

18
19 Temperature modeling results (Section 4.1.2.3) indicate that mean monthly temperatures
20 over the 20-year LTEMP period for all alternatives will be $\leq 14.1^{\circ}\text{C}$ (57.4°F) at Lees Ferry
21 (RM 0) and the confluence with the Little Colorado River (RM 61). Thus, temperature
22 differences among the alternatives are not expected to alter the diatom composition in the Glen
23 Canyon or Marble Canyon reaches of the Colorado River. However, at Diamond Creek RM 225
24 (Grand Canyon reach), mean summer temperatures (July through September) for all alternatives
25 would be high enough (e.g., $\geq 17^{\circ}\text{C}$ [63°F]) to potentially favor adnate diatom species
26 (see Table F-5, Appendix F). Mean monthly temperatures at Diamond Creek would be highest
27 for Alternative F ranging from 18.5 to 20.5°C (65.3 to 68.9°F) and least for Alternatives A and B
28 ranging from 17.2 to 17.5°C (63.0 to 63.5°F). However, increased algae production in the Grand
29 Canyon reach, may not be realized because this reach is strongly light-limited due to higher
30 turbidity levels.

31
32 Section 3.5.2 describes the improved aquatic food base conditions provided by
33 *Cladophora* compared to *Oscillatoria* (types of algae). Light and flow conditions are the primary
34 factors that affect the presence of these organisms in the Colorado River even though modeled
35 monthly temperatures near Lees Ferry and the Little Colorado River otherwise favor the
36 presence of *Cladophora*, which has a favorable temperature range of 13 to 17°C (55 to 63°F),
37 compared to *Oscillatoria*, which has a favorable temperature range of 18 to 21°C (64 to 70°F)
38 (Valdez and Speas 2007). This also applies to the Diamond Creek area, although modeled water
39 temperature conditions in late spring and summer would favor *Oscillatoria* over *Cladophora* for
40 all alternatives, particularly Alternative F where monthly summer temperatures would range
41 from 18.6 to 20.5°C (65.5 to 68.9°F) (see Table F-5, Appendix F). Because conditions at
42 Diamond Creek are already more suitable for *Oscillatoria* (which is more tolerant of turbidity)
43 than *Cladophora*, it would remain more prevalent in the Grand Canyon reach.

44
45 The modeled mean monthly temperatures in the Colorado River downstream of Glen
46 Canyon Dam are within the favorable temperature range for most macroinvertebrates (see

1 Table F-7, Appendix F). However, the modeled mean monthly temperatures for all alternatives
2 for January through April range from 8.7 to 9.9°C (47.7 to 49.8°F) at Lees Ferry, which is below
3 the lowered favorable temperature of 10°C (50°F) for blackflies (Valdez and Speas 2007). The
4 modeled mean monthly temperatures would also be below favorable temperatures for blackflies
5 near the Little Colorado River for February and March. Conversely, modeled monthly
6 temperatures of 17.2 to 20.5°C (63.0 to 68.9°F) for July through August near Diamond Creek
7 under all alternatives would be higher than the upper favorable temperature for planarians 16°C
8 (61°F) (Valdez and Speas 2007).

9
10 Production rates of macroinvertebrates could increase by 3 to 30% for every 1°C (1.8°F)
11 increase in annual temperatures (Valdez and Speas 2007). Temperature modeling results indicate
12 that annual average temperatures would vary among alternatives by $\leq 0.2^\circ\text{C}$ (0.4°F) at Lees
13 Ferry, Little Colorado River, and Diamond Creek. This implies that temperature differences
14 among alternatives are not likely to affect production of aquatic food base organisms. However,
15 comparison of monthly average temperatures indicates a potential small difference among some
16 of the alternatives during the summer at Diamond Creek. Most temperature differences among
17 alternatives would be $< 0.5^\circ\text{C}$ (0.9°F) and therefore not considered significant. However,
18 Alternative F would be as much as 1.5 to 3.0°C (2.7 to 5.4°F) higher than the other alternatives in
19 the summer. Thus, summer macroinvertebrate productivity could be higher under Alternative F
20 compared to the other alternatives.

21
22 A more thorough discussion of potential temperature effects on the aquatic food base is
23 provided in Appendix F.

24 25 26 **4.5.2.2 Nonnative Fish**

27
28 The potential impacts of the alternatives on nonnative fish are described in this section
29 and summarized in Table 4.5.2-1. Because of distinct differences in habitat needs and
30 distributions, impacts on coldwater nonnative fish (trout) and warmwater nonnative fish are
31 considered separately.

32 33 34 **Impacts on Trout**

35
36 Rainbow trout recruitment and population size within the Glen Canyon reach appear to
37 be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999; McKinney, Speas et
38 al. 2001; McKinney, Robinson et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011;
39 Korman, Kaplinski et al. 2011; Korman et al. 2012). Increases in abundance have been attributed
40 to the changes in flows beginning with interim flows in 1991 and later the implementation of
41 MLFF in 1996. These changes both increased minimum flows and reduced fluctuations in daily
42 flows, which created more stable and productive nursery habitats for rainbow trout in Glen
43 Canyon (McKinney et al. 1999). Declines in abundance (such as observed from 2001 to 2007)
44 have been attributed to the combined influence of warmer water releases from Glen Canyon
45 Dam, high abundance and increased competition, and periodic DO deficiencies, along with
46 possible limitations in the food base (Makinster et al. 2007). Increases in recruitment levels and

1 trout abundance in the Glen Canyon reach during 2008 and 2009 are believed to be due to
2 improved habitat conditions and survival rates for YOY rainbow trout resulting from the March
3 2008 HFE (Makinster et al. 2011). Recruitment of rainbow trout in Glen Canyon has been
4 positively and strongly correlated with annual flow volume and reduced hourly flow variation;
5 recruitment has also increased after two of three high-flow releases related to the implementation
6 of equalization flows (Korman et al. 2012). The abundance of rainbow trout within the Glen
7 Canyon reach affects the condition (a measure of the weight-length relationship, or “plumpness”)
8 of rainbow trout in the population. When abundance of rainbow trout is high, their condition
9 typically deteriorates, so large numbers of fish generally also lead to fish of poorer quality to
10 anglers in terms of size and condition (Makinster et al. 2011) and can also lead to declines in
11 abundance.

12
13 Because rainbow trout spawning occurs mostly in the main channel of the Glen Canyon
14 reach, the quality and availability of rainbow trout spawning habitat are expected to be affected
15 by within-day flow fluctuations (McKinney, Speas et al. 2001; Korman, Kaplinski et al. 2011;
16 Korman and Melis 2011), which vary among the alternatives. Within-day flow fluctuations in
17 this reach may act to periodically dewater some spawning areas (redds) while down-ramping
18 may strand larval or YOY rainbow trout (Reclamation 1995; Korman et al. 2005; Korman,
19 Kaplinski et al. 2011; Korman and Melis 2011). Recent captures of young-of-the-year trout in
20 the vicinity of the Little Colorado River confluence suggest that there may be some rainbow
21 trout spawning in lower Marble Canyon; the degree to which spawning and recruitment of trout
22 in this portion of the river might be affected by flow manipulations, including TMFs, is not clear.
23 Mainstem spawning and recruitment of brown trout (*Salmo trutta*) in the Grand Canyon are
24 thought to be limited because of unsuitable temperatures, competition from rainbow trout, and
25 limited availability of suitable habitat for spawning and rearing of YOY trout (Makinster et al.
26 2010; Reclamation 2011a,b). Because brown trout reproduction primarily occurs in tributaries,
27 especially in Bright Angel Creek (Reclamation 2011a, b), their spawning habitats generally
28 would not be affected by the flows associated with any of the alternatives. The following
29 discussion focuses on potential effects of the alternatives on rainbow trout.

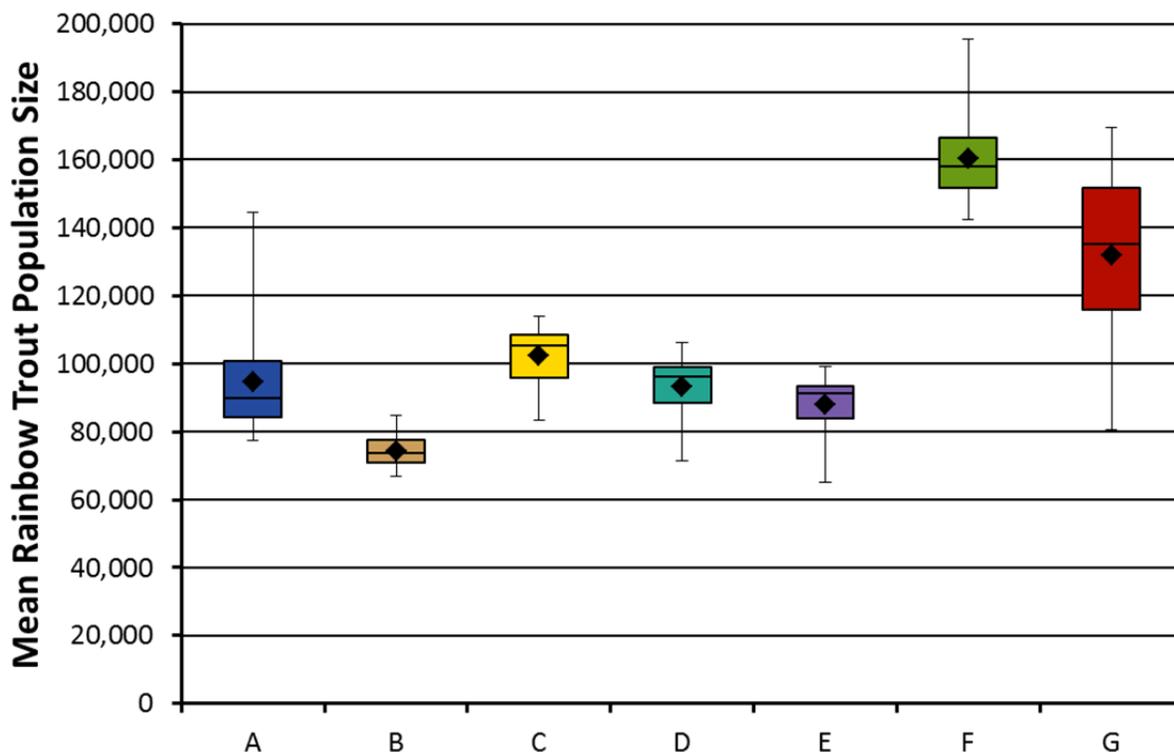
30
31 Evaluation of the stability of rainbow trout spawning habitat for each of the alternatives
32 considered the average allowable daily fluctuation and the evenness of the monthly volumes
33 during the peak spawning months (March through May). Under Alternative A, no changes from
34 current conditions are expected in spawning habitat availability or stability. Rainbow trout
35 spawning habitat would be less stable under Alternatives B and E than under Alternative A
36 because both would allow greater levels of within-day fluctuations during the peak spawning
37 months. Alternative E is expected to have the lowest stability since daily fluctuations and
38 variation in monthly volumes are slightly greater than under Alternative B during the peak
39 spawning months, although the differences are small. Compared to Alternative A, Alternatives D
40 and C would have lower allowable within-day fluctuations, similar or greater monthly volumes,
41 and less variable monthly volumes during the spawning period; as a consequence, rainbow trout
42 spawning habitat availability and stability under Alternatives D and C would be higher than
43 under Alternative A. The two steady flow alternatives (Alternatives F and G) would provide the
44 greatest level of spawning habitat stability.

45

1 Because of differences in down-ramp rates for base operations (i.e., not considering
2 effects of HFEs and TMFs), the potential for stranding of YOY trout is expected to vary among
3 the alternatives (Table 4.5-1). Potential for stranding under Alternative A is expected to be
4 similar to that under current conditions. Stranding potential under Alternative G would be the
5 lowest since there would be no within-day fluctuations for hydropower generation and relatively
6 small down-ramping events between months. Although Alternative F would also exclude within-
7 day fluctuations for hydropower operations, there would be large drops in flows after the annual
8 45,000 cfs spike releases that would occur in May and after the week-long 25,000 cfs high flow
9 that precedes the drop to base flows at the end of June; as a consequence, stranding of YOY trout
10 could be significant under this alternative. Compared to Alternative A, the greatest increase in
11 stranding potential would occur under Alternative B, which has down-ramp rates 100% to 166%
12 higher than any of the other alternatives. Alternatives C, D, and E may have a similar increased
13 stranding potential, with down-ramp rates 66% higher than under Alternative A. As noted above,
14 the degree to which spawning and recruitment of trout in lower Marble Canyon (i.e., in the
15 vicinity of the Little Colorado River) might be affected by flow manipulations, including TMFs,
16 is not clear.

17
18 As described in Section 4.5.1.2, a coupled rainbow trout–humpback chub model, which
19 considers effects of flow variability, annual volumes, HFEs, and TMFs, and effects of annual
20 trout numbers was used to evaluate potential effects of alternatives on the number and average
21 size (length) of rainbow trout in the Glen Canyon reach, on the number of rainbow trout in the
22 Glen Canyon reach exceeding 16 in. in total length, and on the number of age-0 rainbow trout
23 expected to move into the Marble Canyon and Little Colorado River reaches over the 20-year
24 LTEMP period. Among the alternatives, the model estimated average abundances of age-1
25 (i.e., individuals that are 1 year old) and older rainbow trout over the 20-year LTEMP period that
26 ranged from about 65,000 to 196,000 individuals in the Glen Canyon reach (Figure 4.5-1).
27 Although there is a considerable amount of overlap in the ranges of the estimates for some
28 alternatives, the overall estimated average rainbow trout abundance in the Glen Canyon reach
29 was greatest under Alternatives F and G and lowest under Alternative B, with intermediate
30 abundance levels under Alternatives A, C, D, and E.

31
32 The model that predict that annual recruitment of rainbow trout will increase as a
33 function of greater annual volumes, reduced daily variation in flow between May and August,
34 and the occurrence of spring floods (see Appendix F). Modeling indicated that alternatives with
35 more frequent HFEs (especially spring HFEs) would have higher recruitment rates. This increase
36 could lead to increased mean abundance of rainbow trout, but could be offset by TMFs lowered
37 recruitment rates and tended to decrease mean abundance; including both flow actions in an
38 alternative would be expected to result in intermediate levels of trout abundance, with TMFs
39 effectively controlling excess trout produced after HFEs. However, TMFs are considered an
40 experimental action, and it is uncertain whether TMFs would be effective in controlling trout
41 recruitment over the life of the plan. Appendix F presents differences in modeled trout
42 abundance for some alternatives with HFEs and TMFs included or not included as management
43 options. Because of the effects of trout density on growth rates due to competition for food and
44 other resources, it is expected that the average size of rainbow trout would decrease as average
45 population size increases (Korman, Kaplinski et al. 2011). Modeling results indicated that the
46 average size



1

2 **FIGURE 4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the**
 3 **Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives**
 4 **Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum**
 5 **Values for 21 Hydrology Scenarios (Note that diamond = mean; horizontal line = median;**
 6 **lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker =**
 7 **minimum; upper whisker = maximum. Means were calculated as the average for all years**
 8 **within each of the 21 hydrology runs.)**

9

10

11 of age-1 and older rainbow trout over the LTEMP period would be greatest under Alternative B,
 12 smallest under Alternatives F and G, and intermediate under Alternatives A, C, D, and E
 13 (see Appendix F).

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The results of the trout modeling for LTEMP alternatives are consistent with historic observations and previous research, which suggests that recruitment of rainbow trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in years with HFEs (especially spring HFEs), and in years with lower levels of within-day fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012; Section 3.5.4). Equalization flows, which would occur under all alternatives, are also expected to result in increased rainbow trout recruitment during years in which they occur. The high spring flows of Alternative F and spring HFEs would have similar effects on trout recruitment. Considering the frequency of HFEs alone (Table 4.2-1), average annual rainbow trout recruitment would be expected to be highest under Alternatives C, D, F, and G, and would be lowest under Alternatives A and B. It should be noted, however, that the effects of fall HFEs on trout recruitment are less certain and altering assumptions regarding the strength of the relationship between recruitment levels and fall HFEs could significantly

1 affect the modeled results regarding relative effects of alternatives on average numbers of YOY
2 trout, average numbers of trout emigrating to Marble Canyon, and average abundance of age-1
3 and older rainbow trout in the Glen Canyon reach during the LTEMP period.
4

5 Potential increases in rainbow trout recruitment levels due to equalization flows and
6 HFEs could be offset in some years by the proposed testing and implementation of TMFs for all
7 alternatives except Alternative A and F, which do not include TMFs. TMFs are highly variable
8 flows intended to control the number of YOY trout in the Glen Canyon reach (and the associated
9 emigration of trout into Marble Canyon) that would be implemented in years where production
10 of YOY trout is expected to be high. YOY trout tend to occupy shallow habitats near the channel
11 margin (Korman and Campana 2009; Korman and Melis 2011). Based on information from
12 previous studies, raising the flow for a period of days and then suddenly dropping the flow is
13 expected to strand and kill YOY trout, thus controlling numbers and emigration rates (Korman
14 and Melis 2011). As currently envisioned, a typical TMF would consist of several days at a
15 relatively high sustained flow (e.g., 20,000 cfs) followed by a rapid drop to a low flow
16 (e.g., 5,000 cfs), which is held for a brief period (e.g., 6 hr) (Sections 2.2.3.2). This pattern would
17 be repeated for a number of cycles in spring and summer months (May–July). Because of
18 uncertainties about the effectiveness of TMFs, the timing, magnitude, duration, and number of
19 cycles would be tested for efficacy in controlling trout numbers early in the LTEMP period. The
20 number of TMFs that would be expected to occur under each alternative based on modeling are
21 presented in Table 4.9-3 and in Appendix F (Table F-8).
22

23 The number of trout emigrating from the Glen Canyon reach into the Marble Canyon
24 reach of the Colorado River was modeled as a function of recruitment levels, which is related to
25 annual volumes, the occurrence of HFEs, the levels of within-day fluctuations during each water
26 year, and whether TMFs are included as a management option for an alternative. The model
27 estimated that average annual emigration of rainbow trout would be highest under the two steady
28 flow alternatives (Alternatives F [about 72,000 fish/year] and G [about 59,000 fish/year]) and
29 lowest under the alternative with the widest daily fluctuations (Alternative B [about
30 30,000 fish/year]); the model estimated that Alternatives A, C, D, and E would have intermediate
31 levels of rainbow trout emigration (about 37,000 to 44,000 fish/year) (Figure 4.5-2).
32

33 As a measure of the quality of the rainbow trout fishery, the trout model was also used to
34 estimate the average annual number of large rainbow trout (i.e., individuals with total lengths
35 exceeding 16 in.) in the Glen Canyon reach. Among the alternatives, the estimated average
36 number of large rainbow trout in the Glen Canyon reach would range from about 500 to 950 fish
37 (Figure 4.5-3). The estimated average number of large trout present during the 20-year LTEMP
38 period would be greatest under Alternative B (about 870 fish) and lowest under Alternatives F
39 (about 590 fish) and G (about 700 fish), while Alternatives A, C, D, and E would produce
40 intermediate numbers of large trout (about 770, 750, 810, and 830 fish, respectively). In general,
41 growth rates and the number of large rainbow trout in the Glen Canyon reach are expected to be
42 greater in years when overall population abundance is lower due to reduced competition for food
43 and habitat. Because of their effect on recruitment levels and population size, alternatives that

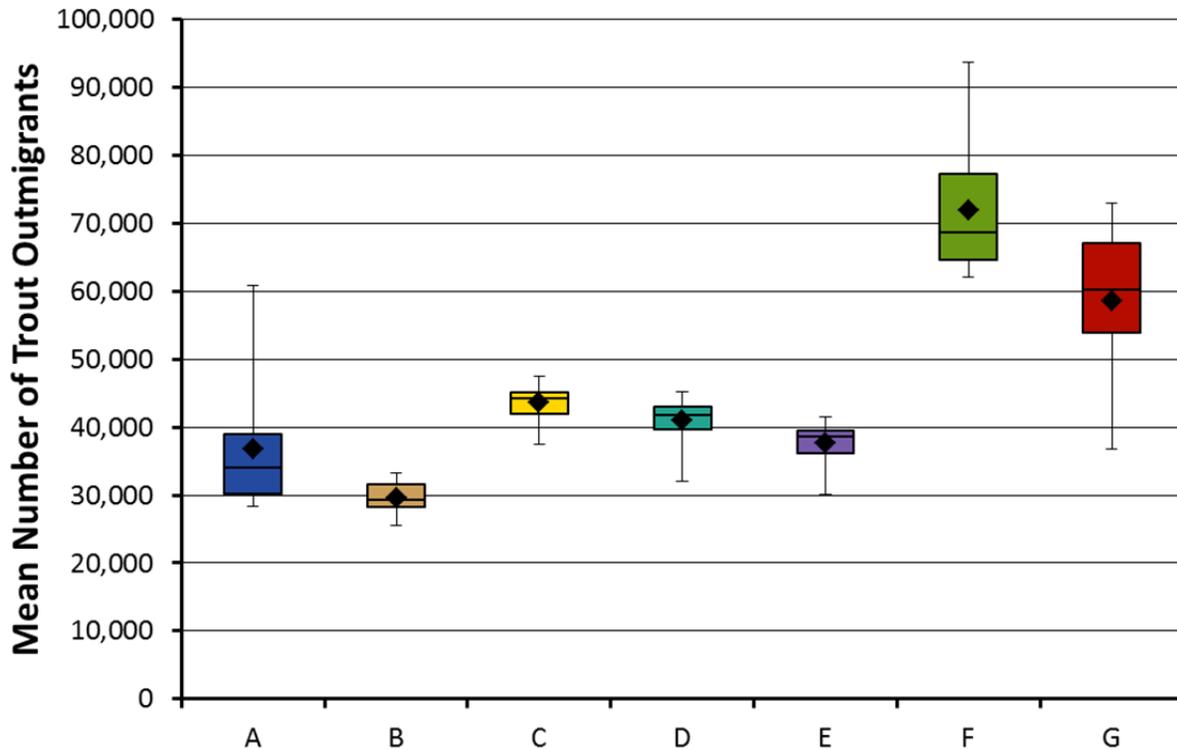
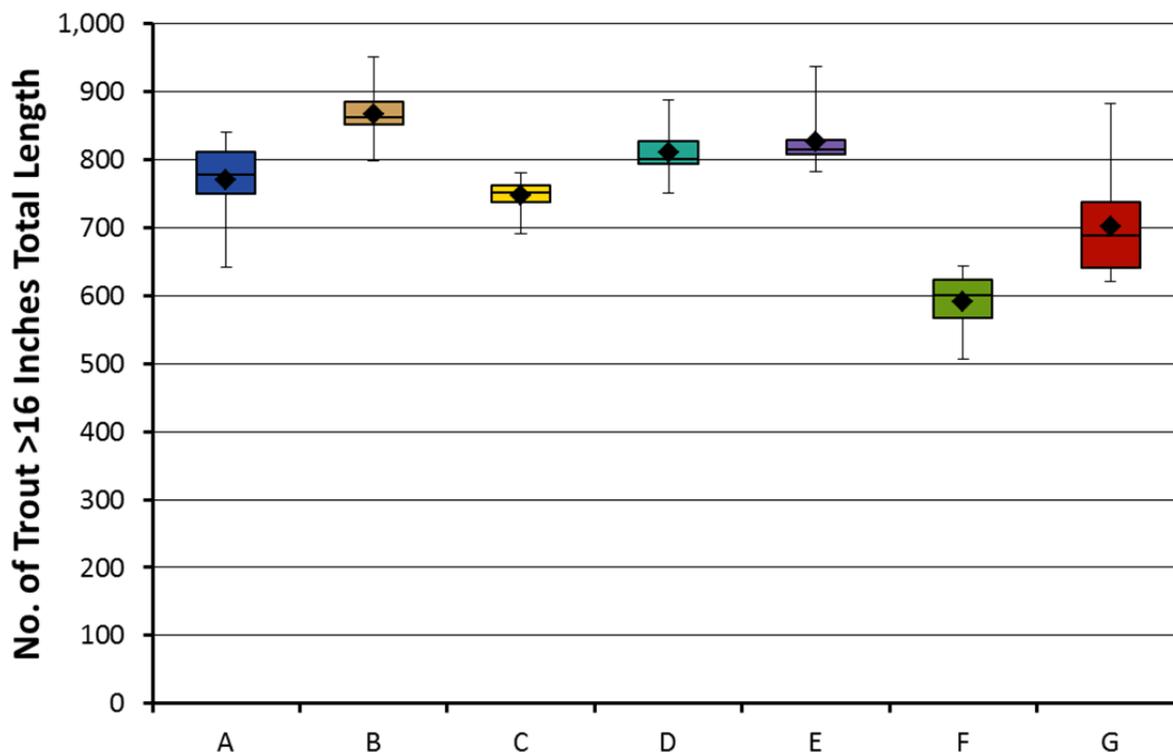


FIGURE 4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

have fewer HFEs (especially spring HFEs), higher daily fluctuations, or implement TMFs are expected to have more large trout.

In general, temperature regimes under all of the alternatives would be suitable, although not optimal, for brown and rainbow trout. Temperature suitability for brown and rainbow trout would be similar among alternatives at most locations downstream of Glen Canyon Dam (Figure 4.5-4), and would be similar to current conditions. However, because of the timing of peak and base flow releases, temperature suitability would be slightly greater under Alternative F than other alternatives at the confluence with the Little Colorado River (RM 61) and lower than other alternatives for locations further downstream. Although main channel temperatures at and downstream of RM 61 would be more suitable for trout than at locations closer to the dam (Figure 4.5-4), the abundance of trout is lower at those locations because other habitat characteristics (e.g., substrate composition and water clarity) are less suitable at these downstream locations.



1

2 **FIGURE 4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon**
 3 **Reach Exceeding 16 in. Total Length during 20-Year Simulation Periods under the LTEMP**
 4 **Alternatives (Note that diamond = mean; horizontal line = median; lower extent of**
 5 **box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum;**
 6 **upper whisker = maximum.)**

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Impacts on Warmwater Nonnative Fish

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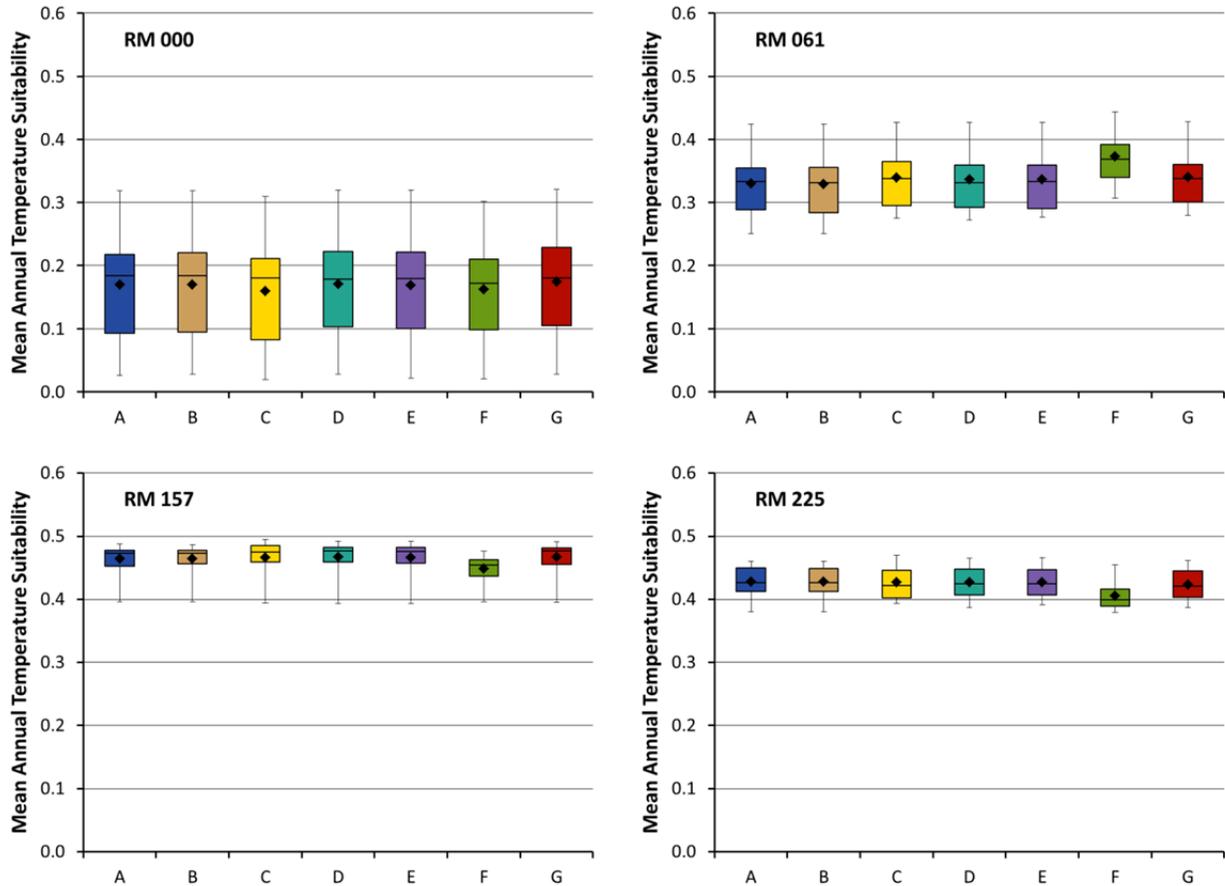
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As described in Section 3.5.4.2, 17 nonnative warmwater fish species have been documented between Glen Canyon Dam and the inflow to Lake Mead (Table 3.5-2). The distribution and abundance of warmwater nonnative fish could be affected by alternative-specific differences in temperature regimes, food production, sediment dynamics, and flow patterns. Of these factors, only the effects on temperature were considered to potentially be large enough to result in impacts on warmwater nonnative fish. To examine this effect, temperature suitability was modeled at various main channel locations for four nonnative warmwater species considered to be representative of the warmwater nonnative fish community (smallmouth bass [*Micropterus dolomieu*], green sunfish [*Lepomis cyanellus*], channel catfish [*Ictalurus punctatus*], and striped bass [*Morone saxatilis*]). In general, the estimated average main channel temperature suitability for these nonnative fish did not differ greatly among the alternatives, and was low under all alternatives; the suitability index was below 0.2 on a scale of 0 to 1 for all seven alternatives (Figure 4.5-5). The modeled temperature suitability indicated that temperature conditions would be most suitable for warmwater nonnative species at locations farther downstream from Glen Canyon Dam (e.g., RM 157 and RM 225) compared to upstream locations (e.g., RM 0 and RM 61); this agrees with past surveys that have found more warmwater nonnative fish species in



1

2 **FIGURE 4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout**
 3 **under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that**
 4 **diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of**
 5 **box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)**

6

7

8 those areas. Relative to current conditions (as exemplified by Alternative A), the temperature

9 suitability model indicated that Alternatives C and F have the greatest potential to improve

10 conditions for warmwater nonnative fish at locations downstream of RM 157, which could result

11 in increased numbers and a greater potential for upstream spread of warmwater nonnative fish

12 species.

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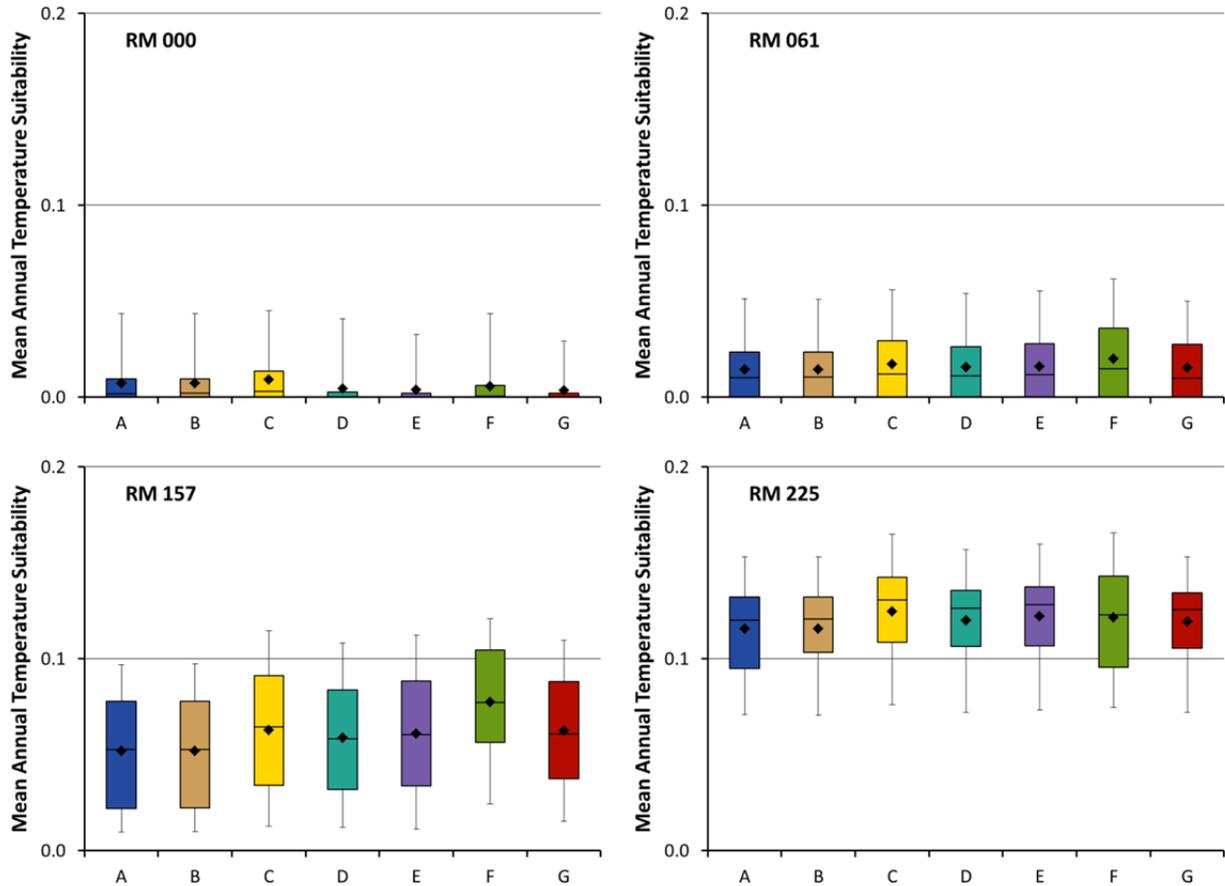
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The Basin Study (Reclamation 2012a) suggested there could be significant increases in temperature and decreases in water supply to the Colorado River system below Glen Canyon Dam over the next 50 years, driven by global climate change. The magnitude of these changes is uncertain. Water elevations in Lake Powell could continue to decline, resulting in release of unprecedentedly warm epilimnetic and metalimnetic water through the penstocks. Summer water releases of up to 30°C water could facilitate establishment of detrimental warmwater fish with correspondingly detrimental impacts on native species, including humpback chub, and on the rainbow trout fishery. Although outside the scope of the LTEMP DEIS, effective management options to address warmwater species threats under this scenario may be limited to construction



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FIGURE 4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish (smallmouth bass, green sunfish, channel catfish, and striped bass) under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

of a hot and cold temperature control device for the hydropower intakes at Glen Canyon Dam or delivery of cooler water via bypass tubes.

4.5.2.3 Native Fish

Humpback Chub

Relatively little spawning and juvenile rearing of humpback chub occurs in the mainstem of the Colorado River, primarily because of relatively cold water (Andersen 2009). This species requires a minimum temperature of 16°C to reproduce, but mainstem water temperatures typically have ranged from 7 to 12°C during the spawning period (Andersen 2009). Drought-induced lower reservoir levels have resulted in warmer releases and mainstem water

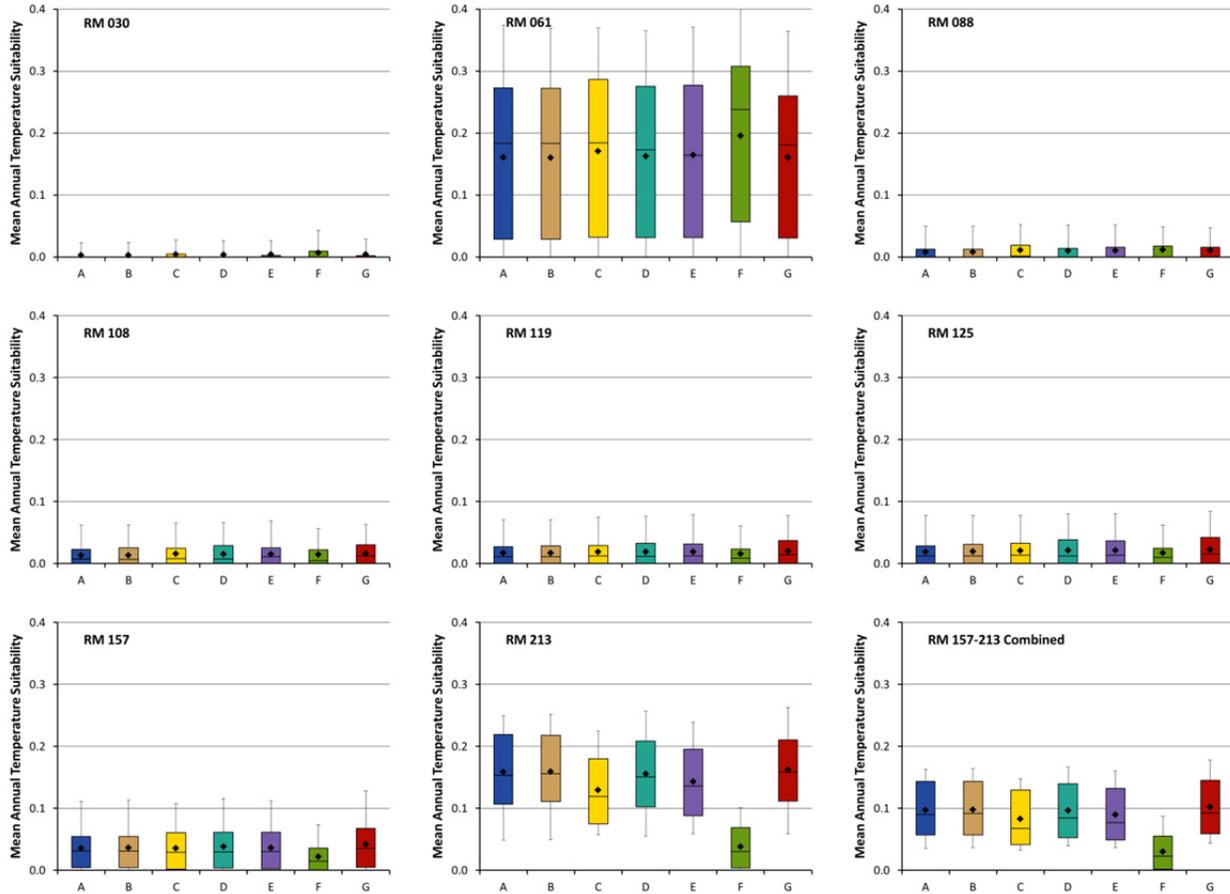
1 temperatures since 2003; temperatures have consistently exceeded 12°C in the summer and fall,
2 and may have played a role in the recent observed increase in the humpback chub population
3 (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014).
4

5 Although survival of larval and juvenile humpback chub in the mainstem was very rare
6 prior to 2000 (Clarkson and Childs 2000), mainstem conditions since the mid-2000s appear to
7 have been suitable for juvenile growth, survival, and recruitment (Yackulic et al. 2014). Warmer
8 water has been shown in the laboratory to increase hatching success, larval survival, and larval
9 and juvenile growth; to improve swimming ability; and to reduce predation vulnerability from
10 rainbow trout (Ward 2011; Ward and Morton-Starner 2015). Yackulic et al. (2014) speculated
11 that when water temperatures are favorable, growth and survival of juveniles in the mainstem
12 will be greater, resulting in increased mainstem recruitment and a larger adult population.
13

14 Under all alternatives, main channel water temperature at humpback chub aggregation
15 areas was estimated to continue to be relatively low for spawning and egg incubation during
16 spring and early summer at most locations downstream of Glen Canyon Dam (Figure 4.5-6).
17 Modeled mean annual main channel temperature suitability for humpback chub at RM 61 (the
18 Little Colorado River confluence) was slightly higher under Alternative F than under the other
19 alternatives (Figure 4.5-6), because the low summer and fall flows of this alternative resulted in
20 warmer water during these months. Because the water warms as it travels downstream from the
21 dam, temperature suitability improves with increasing distance. At RM 213, mean annual
22 temperature suitability was highest under Alternatives A, B, D, and G, and slightly lower under
23 Alternatives C and E (Figure 4.5-6), although overall differences were small among these
24 alternatives. Modeled temperature suitability at RM 213 was lowest under Alternative F
25 (Figure 4.5-6), reflecting the higher, colder flows expected to occur under this alternative during
26 spawning and egg incubation periods (April through June). Based on these results, the combined
27 suitability of mainstem temperatures for spawning, egg incubation, and growth by humpback
28 chub in the downstream-most aggregation sites is anticipated to be negatively affected under
29 Alternative F; however, for the other alternatives, this would remain similar to the low historic
30 levels, as represented by the suitability of Alternative A (the No Action Alternative). It should be
31 noted that, historically, there have been years where the magnitude and timing of mainstem water
32 temperatures have likely coincided to allow spawning and egg incubation to occur in some of the
33 downstream aggregation areas; however, the overall average suitability, as measured by the
34 models used in this analysis, has likely been low.
35

36 Based on temperature-dependent growth relationships developed by Robinson and Childs
37 (2001), mean total lengths of YOY humpback chub at the end of their first growing season
38 would differ little among the alternatives, although values under Alternative F could be slightly
39 higher than under other alternatives (Figure 4.5-7). In addition, YOY humpback chub that rear in
40 the main channel would be expected to reach a greater mean total length (approximately two
41 times longer) by the end of the first calendar year at the Pumpkin Spring aggregation location
42 (RM 213) than at the confluence with the Little Colorado River (RM 61) due to warming of the
43 water as it travels downstream from Glen Canyon Dam (Figure 4.5-7).
44

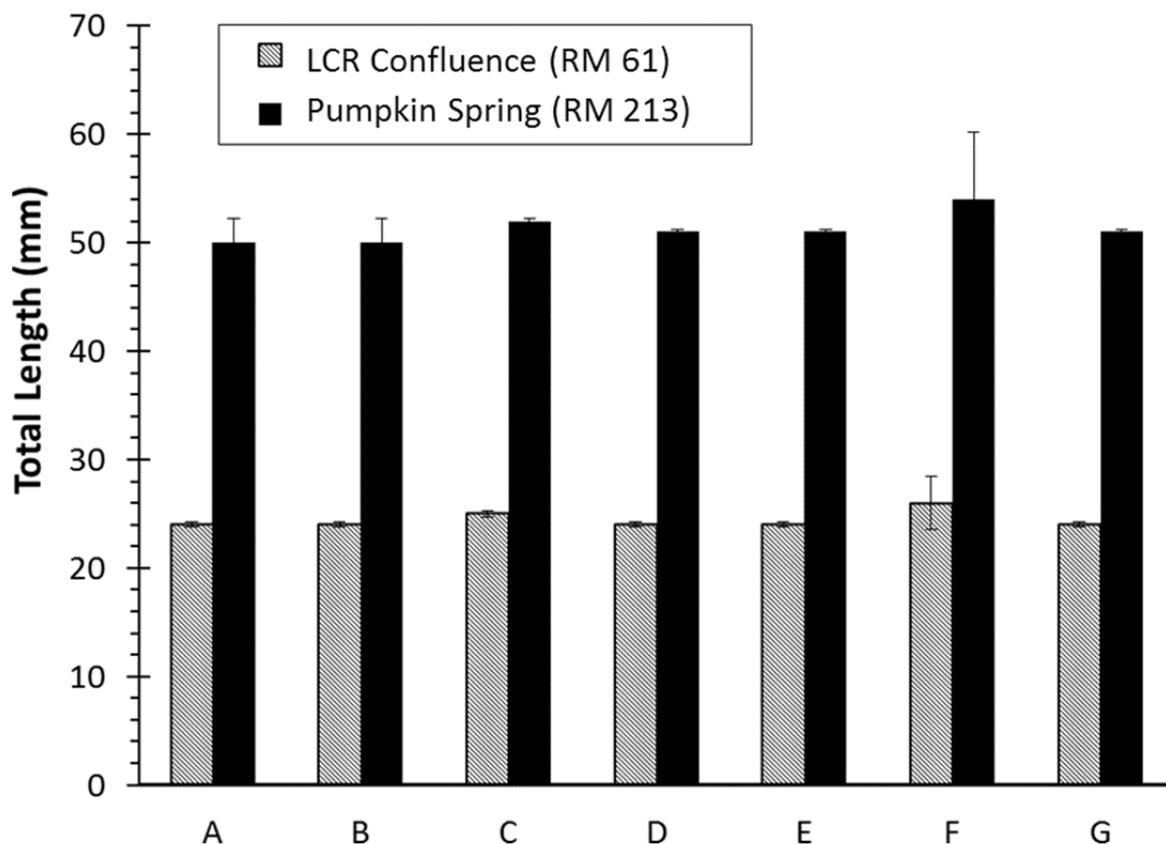
45 HFES, TMFs, and low summer flows would be included in many of the alternatives, but
46 none of these flow actions would result in more than a 1 or 2°C change in



1
 2 **FIGURE 4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under**
 3 **LTEMP Alternatives at Reported Aggregation Locations and Combined Temperature Suitability**
 4 **for RM 157 and RM 213 Locations (Temperature suitability is higher at RM 61 because**
 5 **spawning, incubation, and rearing values are based on temperatures in the relatively warm Little**
 6 **Colorado River where these life history elements occur. Note that diamond = mean; horizontal**
 7 **line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower**
 8 **whisker = minimum; upper whisker = maximum.)**
 9

10
 11 average monthly water release temperatures or downstream water temperatures during periods of
 12 the year considered most important for spawning and egg incubation (i.e., April through June) at
 13 any of the humpback chub aggregation locations.

14
 15 Adult humpback chub numbers were modeled for each alternative under a range of
 16 hydrologic and sediment conditions. Overall, the minimum population sizes observed among the
 17 alternatives during the 20-year simulations ranged from 1,441 to 13,478 humpback chub
 18 (Figure 4.5-8). The lowest modeled minimum adult population size (1,441 fish) was observed
 19 under Alternative F, although the lowest minimum adult population values were relatively
 20 similar among all alternatives (1,441 to 1,912 adult fish). Similarly, the highest minimum
 21 numbers of adult humpback chub were similar among all the alternatives, with values exceeding
 22 13,100 adult fish. The modeled average minimum population size ranged from 4,450 fish under



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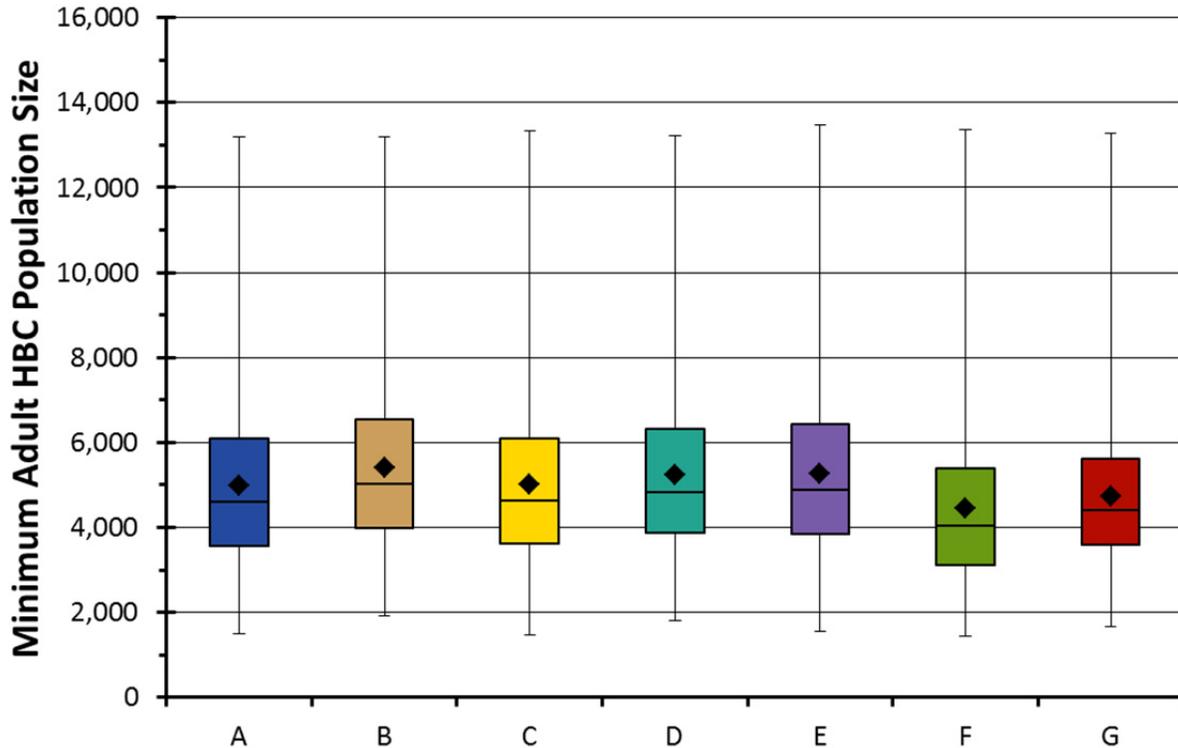
2 **FIGURE 4.5-7 Mean (± 1 standard error [SE]) Modeled Total Length Attained by**
 3 **December 31 for YOY Humpback Chub Based on Predicted Mainstem Water Temperatures**
 4 **at the Little Colorado River Confluence (RM 61) and at Pumpkin Spring (RM 213) under**
 5 **Each Alternative (Note that diamond = mean; horizontal line = median; lower extent of**
 6 **box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum;**
 7 **upper whisker = maximum.)**

8
 9

10 Alternative F to 5,392 fish under Alternative B (Figure 4.5-8). The average minimum number of
 11 adult humpback chub was highest for Alternatives B, D, and E, slightly lower under
 12 Alternatives A and C, and lowest under Alternatives F and G (Figure 4.5-8). These results
 13 indicate that although there are small differences among the alternatives with regard to the
 14 predicted minimum number of adult humpback chub in the Little Colorado River aggregation, all
 15 alternatives would maintain the population above at least 1,000 adults throughout the 20-year
 16 LTEMP period.

17

18 The differences in estimated minimum numbers of adult humpback chub among the
 19 alternatives were related, in part, to the estimated levels of recruitment of rainbow trout in the
 20 Glen Canyon reach, and to the resulting emigration of rainbow trout to the Little Colorado River
 21 reach where survival of YOY and juvenile humpback chub and subsequent recruitment of adult
 22 humpback chub could be affected by increased competition and predation from these trout
 23 (e.g., Yard et al. 2011). As previously discussed, observations indicate that both rainbow trout
 24 recruitment and emigration would increase with implementation of HFES and with reduced



1
 2 **FIGURE 4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year**
 3 **LTEMP Period under LTEMP Alternatives (Note that diamond = mean; horizontal line =**
 4 **median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower**
 5 **whisker = minimum; upper whisker = maximum.)**
 6

7
 8 levels of daily fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012). Alternatives
 9 with the most HFEs over a 20-year period are Alternatives C (mean of 21 HFEs), D (mean of
 10 21 HFEs), F (mean of 19 sediment-triggered HFEs and an additional 19 non-triggered 45,000 cfs
 11 flow spikes in early May), and G (mean of 24 HFEs). Alternatives F and G additionally have no
 12 within-day fluctuations in flows and, consequently, are expected to have the lowest minimum
 13 population levels for adult humpback chub. Although water temperatures will alter the effect of
 14 trout on humpback chub survival and recruitment in some years (e.g., periods when lower
 15 reservoir elevations result in warmer releases), the overall differences in temperature regimes
 16 among the alternatives over the 20-year periods evaluated are expected to be relatively small.
 17 Based on results of laboratory studies on the effects of temperature on predation of humpback
 18 chub by trout (Ward and Morton-Starner 2015), the temperature-mediated differences in
 19 predation rates by trout among the various alternatives would be negligible.
 20

21 TMFs are designed to cause mortality in YOY rainbow trout by inundating low-angle,
 22 near shore habitats for several days, and then quickly reducing dam discharge which would
 23 strand YOY fish. Although TMFs target the Glen Canyon area, where most rainbow trout
 24 production occurs, stage changes from the TMFs also will occur downstream in Marble and
 25 Grand Canyons (see discussion in Section 3.2.1.2). Thus, stranding of native fish further

1 downstream could also occur, including the stranding of endangered humpback chub and
2 razorback sucker.

3
4 Aquatic habitats along the river margin, including backwaters, and other slack water
5 habitats may be important for juvenile native fish rearing because water temperatures may be
6 warmer than in the main channel, and due to the presence of cover such as inundated roots, and
7 overhanging and rooted vegetation. In monthly sampling of randomly selected larval fish
8 habitats from Lava Falls (approx. RM 180) to Lake Mead between March and September, 2014,
9 Albrecht et al. (2014) found that small-bodied YOY native fish catch rates in slack water and
10 channel margins were highest in June through August. Endangered YOY humpback chub were
11 first captured in May and were captured in all months until September, while larval razorback
12 sucker were captured in the first four months of sampling (April–July; Albrecht et al. 2014). In
13 Marble Canyon near the Little Colorado River inflow, Dodrill et al. (2015) showed that juvenile
14 native fish, including humpback chub, can occur in high densities in backwaters and other
15 channel margin habitats.

16
17 The extent of mortality due to stranding of native fish, including endangered species, in a
18 given year in Marble and Grand Canyons as a result of TMFs is unknown, and may depend on
19 the quantity of channel margin habitats and their sensitivity to flow changes, the distribution and
20 abundance of juvenile fish in sensitive habitats, the timing and number of TMFs, and the degree
21 of attenuation of flows downstream. TMFs could be implemented from May through August,
22 and this would overlap with the presence of larval fish for many of the native fish species. Given
23 that razorback sucker spawning was documented for the first time in in the study area in 2014
24 and studies are ongoing, potential impacts on the species are particularly difficult to predict.
25 While indirect benefits of TMFs to native fish as a result of reduced competition and predation
26 by rainbow trout are expected, an unknown number of native fish could also suffer mortality as a
27 result of TMFs, downstream in GCNP. Risk to native fish would likely vary by location
28 depending upon the level of stage changes that would be experienced and the steepness of
29 shallow nearshore areas. Monitoring of the impacts of TMFs throughout GCNP would be
30 implemented to assess effectiveness of the action, as well as the detrimental impacts on native
31 fish and other resources.

32 33 34 **Impacts on Other Native Fish**

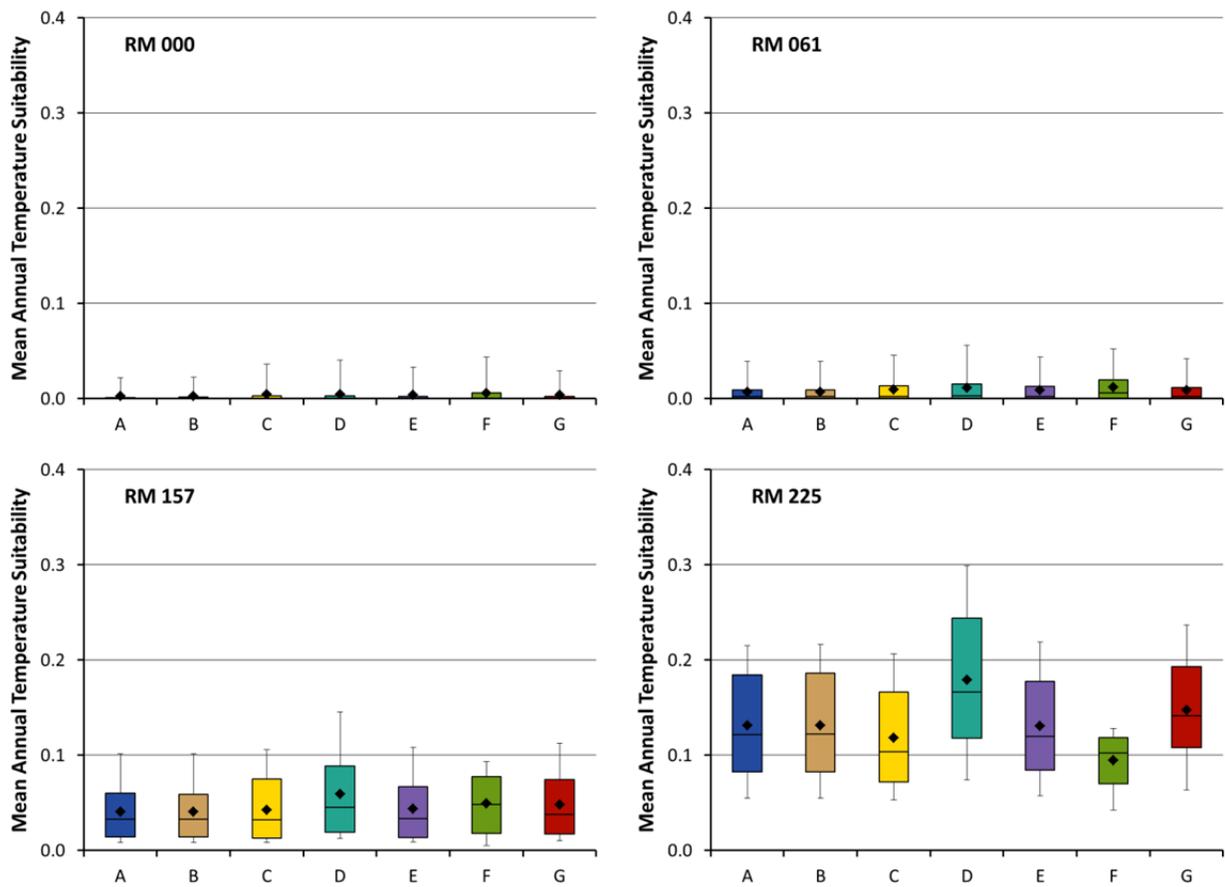
35
36 The distribution and abundance of native fish (other than humpback chub) could be
37 affected by alternative-specific differences in temperature regimes, food production, sediment
38 dynamics, and flow patterns. For the endangered razorback sucker (*Xyrauchen texanus*), suitable
39 water temperatures for spawning, egg incubation, and growth range from 14 to 25°C (FWS
40 2002a), with estimated optimal temperatures of 18°C for spawning, 19°C for egg incubation, and
41 20°C for growth (Valdez and Speas 2007). Hatching success is temperature dependent, with
42 complete mortality occurring at temperatures less than 10°C (AZGFD 2002a). Young razorback
43 suckers require nursery areas with quiet, warm, shallow water such as tributary mouths,
44 backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs
45 (FWS 2002a). During May of 2014, razorback sucker larvae were found in the Colorado River as
46 far upstream as RM 173 (upstream of Lava Falls), which is the farthest upstream razorback

1 sucker spawning has been documented in the Grand Canyon (Albrecht et al. 2014). Additional
2 larval sampling in the lower Grand Canyon found razorback sucker larvae to be distributed
3 throughout most shoreline habitats from Lava Falls to Pearce Ferry from May to July and life
4 stages from larvae through subadults are likely occur within these sections of the river. The
5 highest density of larvae were found in isolated pools, which composed less than 2% of all
6 habitat sampled.(As noted above, TMFs have the potential to strand razorback sucker and other
7 native sucker larvae as well as rainbow trout).

8
9 Two additional species of native suckers—bluehead sucker (*Catostomus discobolus*) and
10 flannelmouth sucker (*C. latipinnis*)—occur in the Colorado River between Glen Canyon Dam
11 and the headwaters of Lake Mead. Bluehead sucker spawning occurs at water temperatures
12 $>16^{\circ}\text{C}$ (AZGFD 2003a; NPS and GCNP 2013); spawning is primarily limited to tributaries. In
13 the Grand Canyon, flannelmouth suckers spawn at water temperatures ranging from 6 to 18°C in
14 or near a limited number of tributaries, especially the Paria and Little Colorado Rivers
15 (AZGFD 2001b; Weiss et al. 1998; Douglas and Douglas 2000), and Bright Angel Creek
16 (Weiss et al. 1998). Flannelmouth sucker larvae, juveniles, and adults were encountered in the
17 mainstem Colorado River of the lower Grand Canyon during surveys conducted in 2014
18 (Albrecht et al. 2014). Spawning may be timed to take advantage of warm, ponded conditions at
19 tributary mouths that occur during high flows in the mainstem Colorado River (Bezzarides and
20 Bestgen 2002). In the tailwaters below Glen Canyon Dam, mainstem water temperatures (8 to
21 12°C) are either at the lower end of or below those needed for spawning and recruitment of
22 flannelmouth suckers. Even though some warming does occur downstream, the relatively cold
23 water in summer is thought to limit survival of YOY fish, recruitment, and condition of this
24 species in the main channel (Thieme et al. 2001; Rees et al. 2005; Walters et al. 2012). Past
25 recruitment in the Colorado River below Glen Canyon Dam of both species was low in the 1990s
26 and then increased after 2000; the largest recruitment estimates coincided with brood years 2003
27 and 2004, when there was an increase in mainstem water temperatures because of warmer
28 releases from Glen Canyon Dam (Walters et al. 2012). From 2008 through 2014, the numbers of
29 flannelmouth suckers captured in electrofishing surveys was greater in mainstem sample
30 locations downstream of RM 109 (Albrecht et al. 2014), perhaps giving an indication of the point
31 at which water temperatures became more suitable for recruitment. The speckled dace is native
32 to all major western drainages from the Columbia and Colorado Rivers south to Mexico
33 (AZGFD 2002c). Within the Grand Canyon, this species occurs within the mainstem Colorado
34 River and its tributaries, including the Little Colorado River (Robinson et al. 1995; Ward and
35 Persons 2006; Makinster et al. 2010). Long-term fish monitoring of the Colorado River below
36 Glen Canyon Dam since 2000 shows the speckled dace to be the third most common fish species
37 (and most common native species) in the river between Glen Canyon Dam and the Lake Mead
38 inflow; it was captured most commonly in western Grand Canyon and the inflow to Lake Mead
39 (Makinster et al. 2010). The speckled dace spawns during the spring to late summer periods
40 (AZGFD 2002c) at temperatures $>17^{\circ}\text{C}$ (NRC 1991).

41
42 To examine the potential of each alternative to produce thermal conditions that could
43 improve reproduction, recruitment, and growth of native fish in main channel habitats,
44 temperature suitability was modeled at various locations downstream from Glen Canyon Dam
45 for the four native fish species other than humpback chub that occur in the river between Glen
46 Canyon Dam and Lake Mead (bluehead sucker, flannelmouth sucker, razorback sucker, and

1 speckled dace [*Rhinichthys osculus*]). In general, the estimated temperature suitability for these
 2 species did not differ greatly among the alternatives, was comparable to suitability under current
 3 operations (Alternative A), and was low for all four species at most locations (Figure 4.5-9). At
 4 RM 225 (Diamond Creek), the mean modeled temperature suitability for native fish was highest
 5 under Alternative D and lowest under Alternative F; the mean temperature suitability levels for
 6 Alternatives A, B, C, E, and G were similar to each other at RM 225 (Figure 4.5-9). Inclusion of
 7 flow actions such as HFEs, TMFs, and low summer flows had only minor influences on modeled
 8 monthly mainstem water temperatures during periods of the year considered most important for
 9 spawning and egg incubation by native fish. As a consequence, these flow actions would have
 10 minor effects on temperature suitability for native fish and would not alter the relative suitability
 11 among alternatives.
 12
 13



14
 15 **FIGURE 4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish (bluehead sucker,**
 16 **flannelmouth sucker, razorback sucker, and speckled dace) under LTEMP Alternatives at Four**
 17 **Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line =**
 18 **median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower**
 19 **whisker = minimum; upper whisker = maximum.)**
 20
 21

4.5.2.4 Aquatic Parasites

The distribution and potential for infestation of aquatic parasites could be affected by alternative-specific differences in temperature regimes, sediment dynamics, and flow patterns. Of these factors, only the effects on temperature were considered to potentially be large enough to result in impacts on aquatic parasites. Temperature suitability was modeled at various locations downstream from Glen Canyon Dam for the four most important parasite species (Asian tapeworm, anchor worm, trout nematode, and whirling disease). Suitability under all alternatives and all species would generally be very low, would not differ at a biologically significant level among alternatives, and would be comparable to conditions under current operations as represented by Alternative A (No Action Alternative; Figure 4.5-10). As a consequence, the relative distributions of aquatic parasites or the effects of aquatic parasites on survival and growth of native fish or trout would not be expected to change relative to current

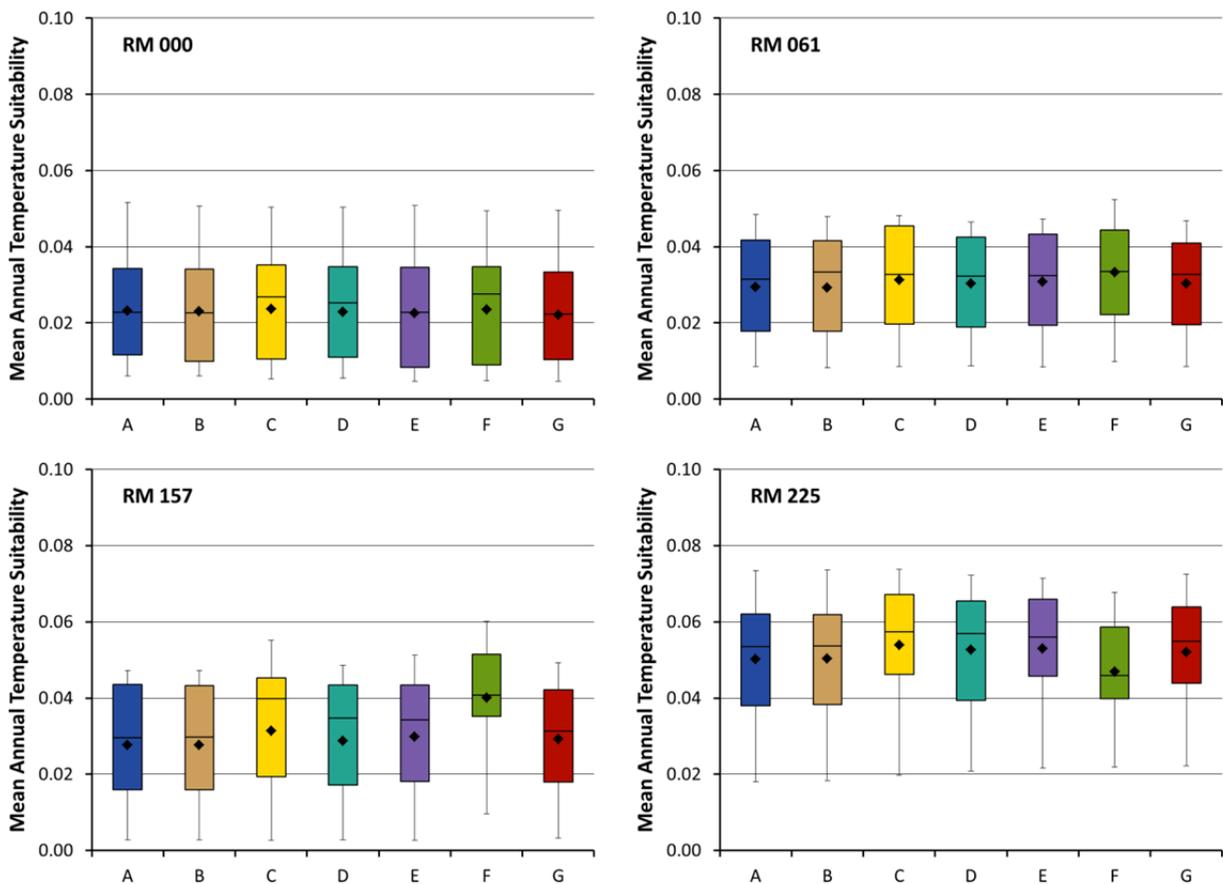


FIGURE 4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives for Aquatic Fish Parasites (Asian tapeworm, anchor worm, trout nematode, and whirling disease) at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

1 conditions under any of the alternatives. Under current conditions, population-level effects of
2 parasites on survival and growth of native fish or trout have not been observed.

3 4 5 **4.5.3 Alternative-Specific Impacts on Aquatic Resources**

6
7 This section describes alternative-specific impacts on aquatic resources, and focuses on
8 assessment results. More detailed descriptions of the basis of impacts and supporting literature
9 citations for these impacts are presented in Section 4.5.2. As described above, none of the
10 alternatives would be expected to noticeably alter temperature suitability for aquatic parasites,
11 and the relative distributions of aquatic parasites and the effects of aquatic parasites on survival
12 and growth of native fish or trout would not be expected to change relative to current conditions
13 under any of the alternatives. For this reason, this topic is not discussed below.

14 15 16 **4.5.3.1 Alternative A (No Action Alternative)**

17 18 19 **Impacts of Alternative A on Aquatic Food Base**

20
21 Alternative A, the No Action Alternative, would continue the implementation of MLFF
22 and other flow and non-flow actions currently in place and, as a consequence, existing conditions
23 and trends in the composition, abundance, and distribution of the aquatic food base is expected to
24 persist over the LTEMP period. That being said, any significant hydrologic changes over the
25 period or inadvertent introductions of nonnative species could result in unanticipated changes.
26 The future impact of the recent introduction of quagga mussels on the aquatic food base is
27 uncertain.

28
29 Dam operations under MLFF have led to increases in the standing mass of food base
30 organisms (i.e., algae and invertebrates) due to steadier flows and greater minimum releases
31 relative to operations prior to 1991. By restricting daily fluctuations in discharge to <8,000 cfs
32 and limiting minimum discharge to 5,000 cfs, the MLFF regime has reduced the size of the varial
33 zone and increased the amount of river bottom that is permanently submerged. Both of these
34 conditions potentially increase the productivity and standing mass of important components of
35 the aquatic food base. Fluctuating flows displace benthic macroinvertebrates into the drift, but
36 they usually recover quickly from such disturbances. The effect of freezing during winter will
37 reduce benthic productivity to the minimum stage level (Shannon et al. 1994; Blinn et al. 1995).
38 The ramping rates for Alternative A would cause a minor increase in drift over the course of a
39 fluctuation, particularly during up-ramping.

40
41 For Alternative A, an average of 5.5 HFEs would occur over the 20-year LTEMP period,
42 with a maximum of 14 HFEs not extending past 2020; see Table 4.2-1). Impacts on the aquatic
43 food base from a spring or fall HFE under Alternative A would be similar to those discussed in
44 Section 4.5.2.1 (e.g., benthic scouring, particularly for HFEs of 41,000 cfs or more, and a shift to
45 invertebrate species more prone to drift such as midges and blackflies). Drifting blackflies and
46 midges are important contributors to the diet of trout. HFEs under Alternative A would only

1 occur through 2020. Therefore, the number of HFES would be less than for the other alternatives
2 (Section 4.2). The cessation of HFES after 2020 may result in a shift back to a food base
3 community not dominated by midges and blackflies (Reclamation 2011a).
4

5 As mentioned in Section 4.5.1.2, trout removal, as would occur under Alternative A,
6 could indirectly increase the availability of invertebrates to native fish by reducing the number of
7 trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for
8 food resources.
9

10 Water temperatures, and their resultant influences on species composition, diversity, and
11 production of the aquatic food base, under the base operations of Alternative A would be similar
12 to current temperatures in the Colorado River downstream of Glen Canyon Dam.
13

14 **Impacts of Alternative A on Nonnative Fish**

15
16 Under Alternative A, no change from current conditions is anticipated. Trout would
17 continue to be supported in the Glen Canyon, Marble Canyon, and Little Colorado River reaches.
18 Warmwater nonnative species would continue to be largely restricted to the lower portions of the
19 river nearer to the headwaters of Lake Mead except in areas where warmer inflows from
20 tributaries provide appropriate temperature regimes, or are sources of nonnative fish, from
21 outside GCNP.
22

23
24 Within-day flow fluctuations (between 5,000 and 8,000 cfs) would continue to affect the
25 stability of spawning habitats for rainbow trout and nearshore habitats for other nonnative fish
26 (Reclamation 1995; Korman et al. 2005; Korman, Kaplinski et al. 2011; Korman and Melis
27 2011), and would result in trout redd exposure and stranding levels similar to those currently
28 occurring. Implementation of spring and fall HFES could result in increased recruitment of
29 rainbow trout in the Glen Canyon reach, followed by increased emigration of trout to the Little
30 Colorado River reach (Wright and Kennedy 2011; Korman et al. 2012). These HFES would not
31 be implemented after 2020 under Alternative A.
32

33 Because of the relatively small number of HFES that would be implemented under this
34 alternative, opportunities for any such increases in trout abundance under Alternative A would be
35 the lowest among all alternatives. TMFs are not included as an explicit element of Alternative A,
36 although some experimentation with TMFs could occur in some years. Mechanical removal of
37 trout at the Little Colorado River confluence, as described in Reclamation (2011a), would be
38 allowed only up through 2020. Modeling indicated that removal of trout might not be effective at
39 limiting the abundance of trout in the Little Colorado River reach because of continued
40 emigration from upstream areas in Marble Canyon. If trout removal is effective, limited benefits
41 to the humpback chub populations in the vicinity of the Little Colorado River could be realized
42 (see Appendix F); other alternatives would allow these management actions to be implemented
43 throughout the entire LTEMP period if tests are deemed successful (e.g., Alternatives B, C, D, E,
44 and G). The modeled average rainbow trout population size in the Glen Canyon reach during the
45 20-year LTEMP period was about 95,000 age-1 and older fish, with an average annual
46 emigration from the Glen Canyon reach to the Marble Canyon reach of about 37,000 fish. The

1 modeled number of large trout (>16 in. total length) averaged about 770 fish under
2 Alternative A.

5 **Impacts of Alternative A on Native Fish**

6
7 Under Alternative A, within-day flow fluctuations (5,000 to 8,000 cfs), and ramp rates
8 (4,000 cfs/hr up ramp and 1,500 cfs/hr down ramp), would continue to affect the stability and
9 quality of nearshore habitats used by native fish, and would not result in a change in current
10 conditions. Mainstem temperature suitability for humpback chub and other native fish would
11 continue to be relatively low in most years.

12
13 Mainstem water temperatures are expected to continue restricting successful reproduction
14 of humpback chub and other native fish to areas warmed by inflows from springs, to tributaries,
15 or to nearshore locations that are far enough downstream for substantial warming to occur
16 (e.g., RM 157 or farther downstream). Under Alternative A, successful spawning, larval survival
17 and growth, and juvenile growth of humpback chub would continue to occur mostly in the Little
18 Colorado River, with possible spawning occurring in Havasu Creek (NPS 2013g) and additional
19 nursery and rearing habitats being used between RM 180 and RM 280 (Albrecht et al. 2014).
20 Successful spawning of razorback sucker has recently been documented as far upstream as Lava
21 Falls in the lower Grand Canyon under current operations (Albrecht et al. 2014) and would be
22 expected to continue to occur under Alternative A, at least in years when temperature regimes
23 are suitable.

24
25 The abundance, distribution, reproduction, and growth of native fishes, including
26 humpback chub, are not expected to change appreciably from current conditions as a result of
27 implementing Alternative A. The estimated average minimum number of adult humpback chub
28 under Alternative A is about 5,000 adult fish over the 20-year LTEMP period, which is similar to
29 the estimated minimum adult humpback chub numbers that have occurred during the period from
30 1989 through 2012 (see Section 3.5.3.1). The estimated absolute minimum number of adult
31 humpback chub over the 20-year LTEMP period is about 1,500. Under Alternative A, it is
32 estimated that YOY humpback chub would achieve a total length of about 24 mm by the end of
33 their first year at RM 61, and about 50 mm at RM 213 if rearing occurred in main channel
34 habitats; fish of these sizes are unlikely to survive the winter in the mainstem. HFEs that could
35 be implemented under this alternative (an average of 5.5 and a maximum of 14 over a 20-year
36 period) would be similar to existing frequencies, so levels of recruitment of rainbow trout in the
37 Glen Canyon reach of the river and numbers of rainbow trout emigrating to downstream reaches,
38 where they may compete with and prey on humpback chub and other native species, would be
39 expected to be unchanged.

42 **Summary of Alternative A Impacts**

43
44 Under Alternative A, existing conditions and trends in the composition, abundance,
45 and distribution of the aquatic food base is expected to persist over the LTEMP period
46 (e.g., increases in the standing mass of food base organisms). The cessation of HFEs after 2020

1 may shift to a food base community not dominated by midges and blackflies. Drifting midges
2 and blackflies are important contributors to the diet of trout. Water temperatures, and their
3 resultant influences on species composition, diversity, and production of the aquatic food base
4 under the base operations of Alternative A, would be similar to current temperatures in the
5 Colorado River downstream of Glen Canyon Dam.

6
7 Under Alternative A, there would be no change from current conditions for nonnative and
8 native fish. HFEs could increase recruitment of rainbow trout in the Glen Canyon reach followed
9 by increased emigration to the Little Colorado reach. However, HFEs would not be implemented
10 after 2020. The modeled average rainbow trout population size during the 20-year LTEMP
11 period was about 95,000 age-1 and older fish, with an average annual emigration from the Glen
12 Canyon reach to the Marble Canyon reach of about 37,000 fish. The modeled number of large
13 trout (>16 in. total length) averaged about 770 fish under Alternative A. Under Alternative A, the
14 estimated average and absolute minimum number of adult humpback chub under Alternative A
15 is about 5,000 and 1,500 adult fish over the 20-year LTEMP period.

16 17 18 **4.5.3.2 Alternative B**

19 20 21 **Impacts of Alternative B on Aquatic Food Base**

22
23 The total wetted area, and therefore the area of main benthic production, for
24 Alternative B would be similar to that of Alternative A because these two alternatives have the
25 same monthly water volumes. However, the greater allowable daily flow fluctuations and more
26 rapid down ramp rates under Alternative B may result in greater instability and reduced quality
27 of backwater and varial zone habitats. Thus, drift rates and stranding within the varial zone may
28 be somewhat higher for Alternative B compared to Alternative A.

29
30 Fluctuating flows (>10,000 cfs/day) can fragment *Cladophora* from its basal attachment
31 and increase its occurrence in the drift. Consuming drifting *Cladophora* (with its attached
32 epiphytes and any invertebrates) allows rainbow trout to expend less energy in searching for food
33 (Leibfried and Blinn 1987). Daily range in flows >10,000 cfs for base operations only occur
34 during December and January (12,000 cfs) for Alternative B.

35
36 Slightly more HFEs would occur during the 20-year LTEMP period under this alternative
37 than under Alternative A (mean of 7.2 vs. 5.5, respectively). Impacts on the aquatic food base
38 from a spring or fall HFE under Alternative B would be similar to those discussed under
39 Alternative A. However, there would not be more than one (spring or fall) HFE every other year.
40 Less frequent HFEs (e.g., less often than annually) may lower the potential for establishing an
41 aquatic food base that is more adaptable to flood conditions (e.g., an increased shift to blackflies
42 and midges). Alternative B would have relatively few HFEs (Table 4.2-1); however, unlike
43 Alternative A, HFEs would be implemented over the entire LTEMP period.

1 Hydropower improvement flows, tested experimentally under Alternative B up to four
2 times in years with ≤ 8.23 maf, could decrease primary and secondary production because of
3 scouring, although macroinvertebrate drift may increase in the short term. Rapid down-ramping
4 may increase stranding of organisms in the varial zone, and this could reduce invertebrate
5 productivity.

6
7 Mechanical removal of trout near the Little Colorado River could indirectly increase the
8 availability of invertebrates to native fish because of reduced competition for food resources.
9 Under Alternative B, TMFs would be tested and implemented, if tests are successful. TMFs
10 could increase drift rates and slightly decrease primary production.

11
12 Water temperatures in the Colorado River under Alternative B would be similar to
13 current temperature conditions because monthly volumes would be identical to those of
14 Alternative A. Therefore, temperature impacts on the aquatic food base would be similar to those
15 for Alternative A.

16 17 18 **Impacts of Alternative B on Nonnative Fish**

19
20 Under Alternative B, trout would continue to be supported in the upper reaches of the
21 river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely
22 restricted to the lower portions of the river and to tributaries. Under Alternative B, habitat quality
23 and stability may be slightly reduced compared to Alternative A. The higher within-day flow
24 fluctuations (6,000–12,000 cfs), and down-ramp rates (3,000–4,000 cfs/hr) could adversely
25 affect the stability of nearshore main channel habitats. The greater within-day flow fluctuations
26 and faster down-ramp rates could also result in greater levels of exposure of trout redds and
27 stranding of YOY rainbow trout. Stability of nearshore habitats under Alternative B could also
28 be negatively affected by inclusion of testing of hydropower improvement flows, which would
29 feature wide daily flow fluctuations (up to a 5,000 to 25,000 cfs range) and would allow
30 increased up- and down-ramp rates. Temperature suitability under Alternative B would be
31 similar to that under Alternative A for both coldwater and warmwater nonnative fish.

32
33 Although slightly more HFEs would occur during the 20-year LTEMP period under this
34 alternative than under Alternative A (mean of 7.2 vs. 5.5, respectively), the estimated abundance
35 and emigration of rainbow trout would be less than under Alternative A (74,000 vs. 95,000
36 average abundance; 30,000 vs. 37,000 average number of emigrants). These lower abundance
37 and emigration numbers reflect the effect of greater within-day flow fluctuations and ramp rates.
38 The number of large trout (>16 in. total length) was estimated to average about 870 fish, which is
39 more than under Alternative A. Inclusion of hydropower improvement flows would be expected
40 to result in even lower trout abundance and emigration and an increase in the numbers of large
41 trout (see Appendix F).

42
43 TMFs would be tested under this alternative and would be implemented for the entire
44 LTEMP period if the tests were deemed successful at limiting rainbow trout recruitment in the
45 Glen Canyon reach. Based on modeling for Alternative B, it is anticipated that TMFs would be
46 triggered in 3 out of 20 years, on average. Alternative B also would allow use of triggered

1 mechanical trout removal at the Little Colorado River for the entire 20-year LTEMP period,
2 whereas such removal would cease after 2020 under Alternative A. Modeling indicates that the
3 inclusion of these actions may be able to reduce the abundance of trout in both the Glen Canyon
4 and Little Colorado River reaches and could benefit the humpback chub population in the
5 vicinity of the Little Colorado River throughout the LTEMP period (see Appendix F). However,
6 the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback
7 chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon.
8 The modeled average trout population size in Glen Canyon under Alternative B was substantially
9 lower than under Alternative A (Figure 4.5-2).

12 **Impacts of Alternative B on Native Fish**

14 Under Alternative B, higher within-day flow fluctuations and down-ramp rates could
15 result in greater instability and reduced quality of nearshore habitats as compared to
16 Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes
17 (Figure 4.5-9) in the mainstem river, as well as estimated growth of YOY humpback chub
18 (Figure 4.5-7), would differ little from suitability and growth under Alternative A.

20 Higher within-day fluctuations during most periods of the year, limitations on the
21 allowable frequency of HFEs, and implementation of TMFs would be expected to reduce
22 recruitment of rainbow trout and the potential for rainbow trout emigration to the Little Colorado
23 River reach (RM 61) compared to Alternative A, which is expected to reduce competition with
24 and predation by rainbow trout on native fishes in that reach (Yard et al. 2011). Alternative B
25 also includes mechanical trout removal near RM 61 for the entire 20-year period, whereas such
26 removal would cease after 2020 under Alternative A.

28 Considering the lower trout recruitment that would result from higher within-day
29 fluctuations, low number of HFEs, and implementation of triggered TMFs, the average modeled
30 minimum number of adult humpback chub (about 5,400 adult fish) is higher under Alternative B
31 than under Alternative A (about 5,000 adult fish). The estimated absolute minimum number of
32 adult humpback chub over the 20-year LTEMP period under Alternative B is about 1,900. While
33 indirect benefits of TMFs to native fish as a result of reduced competition and predation by
34 rainbow trout are expected under this alternative, an unknown number of native fish would also
35 suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in
36 Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented
37 to assess effectiveness of the action, as well as the detrimental impacts on native fish and other
38 resources.

41 **Summary of Alternative B Impacts**

43 Under Alternative B, the area of main benthic food base production would be similar to
44 Alternative A. HFEs conducted less often than annually may lower the potential to establish a
45 food base adaptable to flood conditions (i.e., one dominated by midges and blackflies).
46 Hydropower improvement flows could decrease benthic primary and secondary food base

1 production, although macroinvertebrate drift may increase in the short term. Temperature
2 impacts on the aquatic food base under Alternative B would be similar to those under
3 Alternative A.

4
5 Under Alternative B, habitat quality and stability and temperature suitability for both
6 nonnative and native fish may be slightly reduced compared to Alternative A. The estimated
7 abundance and emigration of rainbow trout under Alternative B would be less than under
8 Alternative A (74,000 vs. 95,000 average abundance; 30,000 vs. 37,000 average number of
9 emigrants). The number of large trout (>16 in. total length) was estimated to average about
10 870 fish, which is more than the 770 fish estimated under Alternative A. Estimated growth of
11 YOY humpback chub under Alternative B would be similar to Alternative A. The average
12 modeled minimum number of adult humpback chub over the LTEMP period (about 5,400 adult
13 fish) is slightly higher under Alternative B than under Alternative A (about 5,000 adult fish). The
14 estimated absolute minimum number of adult humpback chub under Alternative B is about
15 1,900 compared to 1,500 for Alternative A.

16 17 18 **4.5.3.3 Alternative C**

19 20 21 **Impacts of Alternative C on Aquatic Food Base**

22
23 Compared to Alternative A, Alternative C has higher monthly release volumes (and thus
24 higher benthic biomass) from December through June, and lower volumes (and thus lower
25 benthic biomass) from August through November. The daily range in flows would be lower
26 under Alternative C compared to Alternative A. Therefore, benthic productivity may be
27 somewhat increased particularly in the Glen Canyon reach because less of the benthic substrate
28 would be exposed during fluctuation cycles. Increased benthic productivity would result in long-
29 term increases in benthic drift (Kennedy, Yackulic et al. 2014).

30
31 Impacts on the aquatic food base from a spring or fall HFE under Alternative C would be
32 similar to those discussed under Alternative A. Unlike Alternative A, HFEs would be
33 implemented for the entire LTEMP period, with an average of 21.3 HFEs (maximum 40 HFEs)
34 (Table 4.2-1). The more frequent HFEs are expected to favor blackfly and midge production.
35 Proactive spring HFEs with maximum possible 24-hr release up to 45,000 cfs may be
36 implemented under Alternative C in equalization years (years with annual volumes ≥ 10 maf) if
37 no other spring HFE occurs in the same water year. Although a proactive spring HFE may scour
38 the benthic community, particularly in the Glen Canyon reach, it would also increase the aquatic
39 food base (e.g., blackflies and midges) available to drift-feeding fishes in the short term and
40 may help control New Zealand mudsnail populations (Rosi-Marshall et al. 2010;
41 Kennedy et al. 2013).

42
43 Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum
44 of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. Fall
45 HFEs longer than 96 hr (i.e., maximum of 137 hr) could be implemented under Alternative C.
46 The HFE volume would be limited to that of a 45,000 cfs, 96-hr flow. Thus, these extended-

1 duration HFEs would be of lower magnitude and produce less benthic scouring, assuming less
2 shoreline sediments would be affected by flows less than 45,000 cfs. Drift during an HFE longer
3 than 96 hr may be elevated due to increased biomass of benthic invertebrates that may develop
4 over the summer months. HFEs longer than 96 hr may help to control the abundance of New
5 Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream
6 abundance, although abundance in the 250-km stretch of river above Lake Mead tends to be
7 more than an order of magnitude less than in the 110-km stretch below Glen Canyon Dam
8 (Shannon, Benenati et al. 2003).

9
10 Steady flows would occur just prior to and after spring or fall HFEs under Alternative C.
11 These flows could result in several months of maximized benthic production in the mainstem and
12 possible maintenance and development of planktonic and benthic production in shoreline areas,
13 especially backwaters. Benthic productivity in the mainstem should also increase under steady
14 flows.

15
16 Tests and implementation of low summer flows would be conducted under Alternative C
17 if conditions warrant it. Since some fluctuation would still be allowed during these tests, overall
18 food base production is expected to be less than that which would occur under higher flow
19 conditions.

20
21 Trout removal, as would occur under Alternative C, could indirectly increase the
22 availability of invertebrates to native fish by reducing the number of trout near the confluence of
23 the Little Colorado River (RM 61), thereby reducing competition for food resources. Under
24 Alternative C, TMFs would be tested and implemented, if tests are successful. TMFs could
25 temporarily increase drift rates and slightly decrease primary production.

26
27 The slightly warmer mean monthly water temperatures under Alternative C at RM 225
28 may slightly increase benthic production compared to Alternative A as modeled temperatures
29 would be 18.1 and 18.2°C (64.6 and 64.8°F) for August and September, respectively, compared
30 to 17.2 and 17.4°C (63 and 63.3°F). In addition to favoring adnate diatoms over stalked diatoms,
31 these slightly warmer temperatures would tend to favor *Oscillatoria* over *Cladophora*. Overall,
32 these changes would be considered detrimental to the aquatic food base (Section 4.5.2.1).
33 Otherwise, temperature impacts on the aquatic food base would be similar to those described for
34 Alternative A (Section 4.5.3.1).

35 36 37 **Impacts of Alternative C on Nonnative Fish**

38
39 Under Alternative C, trout would continue to be supported primarily in the upper reaches
40 of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be
41 largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A,
42 habitat quality and stability for nonnative fish may be higher because of smaller within-day flow
43 fluctuations. However, stranding of YOY rainbow trout may be slightly higher than under
44 Alternative A due to slightly greater down-ramp rates. Temperature suitability under
45 Alternative C was estimated to be similar that under Alternative A for trout at all locations

1 (Figure 4.5-4), but could slightly improve conditions for warmwater nonnative fish at the
2 locations farthest downstream compared to Alternative A (Figure 4.5-5).

3
4 Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum
5 of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. The
6 greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may
7 strongly favor trout recruitment, together with reduced fluctuations, could result in higher
8 rainbow trout recruitment and emigration rates (see discussion of effects of HFEs on nonnative
9 fish in Section 4.5.2.2). TMFs would be tested under this alternative and would be implemented
10 for the entire LTEMP period if they were deemed successful at limiting rainbow trout
11 recruitment in the Glen Canyon reach. Based on modeling for Alternative C, it is anticipated that
12 TMFs would be triggered in 6 out of 20 years, on average. This alternative has the highest
13 estimated number of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about
14 44,000 fish), and the fewest large rainbow trout (about 750 fish) relative to all of the other non-
15 steady flow alternatives, even though implementation of TMFs is included as an element of the
16 alternative.

17 18 19 **Impacts of Alternative C on Native Fish**

20
21 The quantity, quality, and stability of nearshore habitats would be affected less under
22 Alternative C than under Alternative A. Within-day flow fluctuations would be scaled according
23 to monthly volumes (3,500 to 6,000 cfs during average hydrologic conditions) and would be less
24 under this alternative than under Alternative A. However, improvements to habitat stability that
25 may result from reduced fluctuations may be offset, in part, by the higher down-ramp rates
26 (2,500 cfs/hr). Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes
27 (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ
28 little from suitability and growth predicted for Alternative A.

29
30 The relatively high number of HFEs under Alternative C would be expected to increase
31 the abundance of trout and the number of emigrants to the Little Colorado River reach, with
32 potential adverse effects on humpback chub. The potential for competition with and predation on
33 humpback chub could be offset by mechanical removal of trout in the Little Colorado River
34 reach (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However,
35 the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback
36 chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon.
37 The estimated average minimum number of adult humpback chub under Alternative C would be
38 similar to that under Alternative A (about 5,000 adult fish) and slightly less than under
39 Alternatives B, D, and E. The estimated average minimum number of adult humpback chub
40 under Alternative C would be greater than under Alternatives F and G. The estimated absolute
41 minimum number of adult humpback chub over the 20-year LTEMP period under Alternative C
42 is about 1,500, the same as Alternative A. While indirect benefits of TMFs to native fish as a
43 result of reduced competition and predation by rainbow trout are expected under this alternative,
44 an unknown number of native fish would also suffer mortality as a result of TMFs, downstream
45 in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs

1 throughout GCNP would be implemented to assess effectiveness of the action, as well as the
2 detrimental impacts on native fish and other resources.
3
4

5 **Summary of Alternative C Impacts**

6

7 Under Alternative C, benthic food base productivity may be higher in December through
8 June due to higher flows, but lower from August through November due to lower flows
9 compared to Alternative A. The more frequent HFEs compared to Alternative A favor the
10 production of midges and blackflies. Slightly warmer water temperatures for August and
11 September at RM 225 under Alternative D may slightly increase food base production compared
12 to Alternative A, although this could be offset by change in diatoms from stalked to adnate forms
13 and favoring *Oscillatoria* over *Cladophora*.
14

15 Under Alternative C, habitat quality and stability for nonnative and native fish may be
16 higher than under Alternative A because of smaller within-day flow fluctuations. However,
17 stranding of YOY rainbow trout may be slightly higher. Temperature suitability under
18 Alternative C would be similar to Alternative A for trout, native fishes, and growth of YOY
19 humpback chub; but could slightly improve conditions for warmwater nonnative fish at the
20 locations farthest downstream from Glen Canyon Dam. The greater number of HFEs, coupled
21 with reduced fluctuations, under Alternative C compared to Alternative A could result in higher
22 rainbow trout recruitment and emigration rates. Alternative C has the highest estimated number
23 of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about 44,000 fish), and the
24 fewest large rainbow trout (about 750 fish) relative to all of the other non-steady flow
25 alternatives. The estimated average minimum number of adult humpback chub under
26 Alternative C would be similar to that under Alternative A (about 5,000 adult fish); while the
27 estimated absolute minimum number of adult humpback chub under Alternative C is about the
28 same as Alternative A (1,500 fish).
29
30

31 **4.5.3.4 Alternative D (Preferred Alternative)**

32
33

34 **Impacts of Alternative D on Aquatic Food Base**

35

36 Under Alternative D, monthly release volumes would be relatively consistent throughout
37 the year compared to Alternative A. This would produce a more consistent and stable aquatic
38 food base. Daily range in flows would be similar to, but slightly lower under Alternative D
39 compared to Alternative A. Therefore, benthic productivity may be somewhat increased,
40 particularly in the Glen Canyon reach, because less of the benthic substrate would be exposed
41 during fluctuation cycles. Stranding within the varial zone may be somewhat lower under
42 Alternative D compared to Alternative A as a result. Increased benthic productivity would
43 increase drift in the long term (Kennedy, Yackulic et al. 2014).
44
45

1 Under Alternative D, there would be an average of 19.3 HFEs (maximum of 38 HFEs)
2 (Table 4.2-1). The more frequent HFEs are expected to favor blackfly and midge production.
3 Spring HFEs may not be tested in years when there appear to be unacceptable risks to key
4 resources including the aquatic food base. Impacts on the aquatic food base from a proactive
5 spring HFE would be similar to those under Alternative C (Section 4.5.3.3).
6

7 Under Alternative D, up to four of the fall HFEs could be long-duration HFEs (lasting up
8 to 250 hr). These extended-duration HFEs would be of higher magnitude and could produce
9 more benthic scouring than the extended-duration HFEs for Alternative C. Drift from an
10 extended-duration fall HFE may be elevated due to increased biomass of benthic invertebrates
11 that may develop over the summer months. HFEs longer than 96 hr could help to control the
12 abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to
13 their downstream abundance. The 4 to 5 months between a fall and spring HFE could preclude
14 full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE,
15 particularly a long-duration HFE, could scour the remaining primary producers and susceptible
16 invertebrates and further delay the recovery of the aquatic food base. For this reason,
17 implementation of a spring HFE in years that follow an extended duration fall HFE would be
18 carefully considered.
19

20 Steady flows would occur after significant sediment input before fall HFEs, as well as for
21 the remainder of the month in which the HFE occurred. Impacts on the aquatic food base would
22 be similar to those under Alternative C (Section 4.5.3.3).
23

24 Tests of low summer flows would be conducted under Alternative D in the second
25 10 years of the LTEMP if conditions warrant it (as described in Section 2.2.4). Since some
26 fluctuation would still be allowed during these tests, overall food base production is expected to
27 be less than that which would occur under higher flow conditions.
28

29 Trout removal, as would occur under Alternative D, could indirectly increase the
30 availability of invertebrates to native fish by reducing the number of trout near the confluence of
31 the Little Colorado River (RM 61), thereby reducing competition for food resources. Under
32 Alternative D, TMFs would be tested and implemented, if tests are successful. TMFs could cause
33 short-term increases in drift rates and slightly decrease primary production.
34

35 An aquatic resource-related experiment unique to Alternative D would be to test the
36 effects of sustained low weekend flows in May through August on benthic invertebrate
37 production and diversity. It has been hypothesized that the large varial zone created by
38 fluctuating flows limits recruitment of mayflies (order Ephemeroptera), stoneflies (order
39 Plecoptera), and caddisflies (order Trichoptera), collectively referred to as EPT (Ephemeroptera-
40 Plecoptera-Trichoptera), due to high egg mortality. For example, adult females of the mayfly
41 genus *Baetis* land on rocks protruding from the water surface and then crawl underwater to lay
42 their eggs on the underside of the rock. These rocks may become dry for up to 12 hr during a
43 fluctuation cycle, causing mortality of the mayfly eggs (Kennedy 2013). If EPT deposit eggs
44 principally along the shallower shoreline areas, then eggs laid during stable low flows over the
45 weekend may not be subjected to drying prior to their hatching. Depending on the findings from
46 the first test, this experiment could be repeated during the LTEMP period. In addition to

1 potentially increasing EPT, sustained low weekend flows may benefit other aquatic food base
2 organisms that have terrestrial adult life stages, such as dragonflies and true flies (including
3 midges and blackflies). Some loss of benthic production is expected in the shoreline areas that
4 remain dewatered over the weekend. If this results in an unacceptable risk to overall benthic
5 production, the experiment might not be repeated.

6
7 Temperature impacts on the aquatic food base under Alternative D would be similar to
8 those under Alternative C (Section 4.5.3.3).

9 10 11 **Impacts of Alternative D on Nonnative Fish**

12
13 Under Alternative D, trout would continue to be supported primarily in the upper reaches
14 of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be
15 largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A,
16 habitat quality and stability for nonnative fish is expected to be slightly higher because of
17 slightly lower within-day flow fluctuations, especially during the winter. Stranding of YOY
18 rainbow trout may be slightly higher than under Alternative A due to slightly greater down-ramp
19 rates. Temperature suitability for trout under Alternative D was estimated to be similar to that
20 under Alternative A at all locations (Figure 4.5-4), but could improve slightly compared to
21 Alternative A for warmwater nonnative fish at the locations farthest downstream (Figure 4.5-5).

22
23 Alternative D has a much higher number of HFEs (average of 21 HFEs and a maximum
24 of 38 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. This
25 greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may
26 strongly favor trout recruitment, could result in higher rainbow trout abundance and emigration
27 rates (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). This alternative is
28 expected to result in average rainbow trout numbers of about 93,000 age-1 and older fish and
29 810 large rainbow trout, similar to those estimated for Alternative A, suggesting that inclusion of
30 TMFs would offset the increased recruitment that would be anticipated with a greater occurrence
31 of HFEs (see Appendix F). However, modeling results suggest that the number of trout
32 emigrating into Marble Canyon under Alternative D (about 41,000 fish) would be about 11%
33 higher, on average, than under Alternative A (about 37,000 fish) (Figure 4.5.2). TMFs would be
34 tested under this alternative and would be implemented for the entire LTEMP period if they were
35 deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on
36 modeling for Alternative D, it is anticipated that TMFs would be triggered in about 4 out of 20
37 years, on average.

38
39 Alternative D is the only alternative to include low benthic flows for invertebrate
40 production which includes low benthic flows for invertebrate production (low stable flows every
41 weekend, May-August). These flows could have both beneficial and adverse effects to the
42 aquatic food base which could either increase or decrease nonnative fish abundance.

1 **Impacts of Alternative D on Native Fish**
2

3 The quantity, quality, and stability of nearshore habitats would be affected less under
4 Alternative D than under Alternative A because within-day flow fluctuations would be slightly
5 less under this alternative than under Alternative A, especially during winter. Mainstem
6 temperature suitability for humpback chub (Figure 4.5-6) and growth of YOY humpback chub
7 under predicted mainstem temperatures (Figure 4.5-7) are expected to differ little from suitability
8 and growth predicted for Alternative A. Temperature suitability for other native fish could
9 improve slightly compared to under Alternative A (Figure 4.5-9) because, under Alternative D, it
10 is predicted that monthly volumes would result in more favorable mainstem temperatures at
11 downstream locations (e.g., RM 225) during early summer months when spawning and egg
12 incubation would benefit.
13

14 The relatively high number of HFEs under Alternative D would normally be expected to
15 increase the recruitment levels for trout and the number of emigrants to the Little Colorado River
16 reach (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). As discussed
17 above, even though TMFs that would be implemented (when triggered by high predicted levels
18 of recruitment) throughout the LTEMP period may result in smaller average trout population size
19 in the Glen Canyon Reach, the model indicated that emigration of trout to the Marble Canyon
20 reach under Alternative D would increase, on average, by about 11% compared to Alternative A.
21 This increases the potential for trout to occur in the Little Colorado River reach where humpback
22 chub survival and growth could be affected. The potential for competition with and predation on
23 humpback chub by trout is expected to be partially offset by allowing mechanical removal of
24 trout in the Little Colorado River reach when triggering conditions are met (see discussion of
25 effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout
26 numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-
27 lived due to ongoing emigration from areas upstream in Marble Canyon. Based on modeling, the
28 estimated average minimum number of adult humpback chub under Alternative D (about
29 5,200 adult fish) would be about 4% higher than under Alternative A; 1 and 3% lower than under
30 Alternatives E and B, respectively; and 11 and 18% higher than under Alternatives G and F,
31 respectively (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub
32 over the 20-year LTEMP period under Alternative D is about 1,800. While indirect benefits of
33 TMFs to native fish as a result of reduced competition and predation by rainbow trout are
34 expected under this alternative, an unknown number of native fish would also suffer mortality as
35 a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring
36 of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the
37 action, as well as the detrimental impacts on native fish and other resources.
38

39 Alternative D is the only alternative to include low benthic flows for invertebrate
40 production which includes low benthic flows for invertebrate production (low stable flows every
41 weekend, May-August). As described above, these flows could have both beneficial and adverse
42 effects to food base which could either increase or decrease native fish abundance.
43
44

1 **Summary of Alternative D Impacts**
2

3 The relatively similar month-to-month release volumes under Alternative D compared to
4 Alternative A would produce a more consistent and stable aquatic food base. The more frequent
5 HFEs under Alternative D are expected to favor midge and blackfly production compared to
6 Alternative A. Sustained low weekend flows in May through August under Alternative D would
7 be tested to determine if they increase benthic food base production and diversity including the
8 recruitment of mayflies, stoneflies, and caddisflies (important food base organisms currently rare
9 to absent throughout much of the mainstem below Glen Canyon Dam). Temperature impacts on
10 the aquatic food base under Alternative D would be similar to those under Alternative C.
11

12 Under Alternative D, habitat quality and stability for nonnative and native fish are
13 expected to be slightly higher than under Alternative A. Stranding of YOY rainbow trout may
14 also be slightly higher than under Alternative A. Temperature suitability for trout, humpback
15 chub, and growth of YOY humpback chub under Alternative D would be similar to that under
16 Alternative A, but could slightly improve suitability for warmwater nonnative fish and other
17 native fish. The high number of HFEs could result in higher rainbow trout abundance and
18 emigration rates. Alternative D is expected to result in average rainbow trout numbers of about
19 93,000 age-1 and older fish and 810 large rainbow trout, similar to those estimated for
20 Alternative A. However, modeling results suggest that the number of trout emigrating into
21 Marble Canyon under Alternative D (about 41,000 fish) would be about 11% higher, on average,
22 than under Alternative A (about 37,000 fish). The estimated average minimum numbers of adult
23 humpback chub under Alternative D (about 5,200 adult fish) would be higher than under
24 Alternative A (5,000 adult fish). The estimated absolute minimum number of adult humpback
25 chub over the LTEMP period under Alternative D is about 1,800 compared to 1,500 under
26 Alternative A.
27
28

29 **4.5.3.5 Alternative E**
30

31 **Impacts of Alternative E on Aquatic Food Base**
32

33 More even monthly release volumes would improve aquatic food base productivity
34 compared to Alternative A. However, this benefit could be offset by increased daily fluctuations,
35 which would strand invertebrates within the varial zone. Higher daily fluctuations may also
36 cause short-term increases in drift.
37
38

39 Under Alternative E, fall HFEs would be allowed throughout the 20-year LTEMP period,
40 while spring HFEs would be allowed for the last 10 years of the LTEMP period with an average
41 of 17.1 HFEs (maximum of 30 HFEs) (Table 4.2-1). The frequent HFEs will favor blackfly and
42 midge production. The number of HFEs would be less than under Alternative C because there
43 would be no spring HFEs in the first 10 years (see Section 2.3). Steady flows would occur after
44 significant sediment inputs prior to fall HFEs under Alternative E. Consequently, there could be
45 several months of improved benthic production in the mainstem and possible maintenance and
46 development of planktonic and benthic production in shoreline areas, especially backwaters.

1 Tests of low summer flows would be conducted under Alternative E in the second
2 10 years of the LTEMP if conditions warrant (as described in Section 2.2.5). Since some
3 fluctuation would still be allowed during these tests, overall food base production is expected to
4 be less than that which would occur under higher flow conditions.
5

6 Trout removal, as would occur under Alternative E, could indirectly increase the
7 availability of invertebrates to native fish by reducing the number of trout near the confluence of
8 the Little Colorado River (RM 61), thereby reducing competition for food resources. Under
9 Alternative E, TMFs would be tested and implemented, if tests are successful. TMFs could
10 increase cause short-term increases in drift rates and slightly decrease primary production.
11

12 Temperature impacts on the aquatic food base for Alternative E would be similar to those
13 under Alternative C (Section 4.5.3.3).
14

15 **Impacts of Alternative E on Nonnative Fish**

16

17
18 Under Alternative E, trout would continue to be supported primarily in the upper reaches
19 of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be
20 largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A,
21 habitat quality and stability for nonnative fish would be slightly lower due to increased levels of
22 within-day fluctuations during most months. Stranding of YOY rainbow trout may also be
23 slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature
24 suitability under Alternative E would be similar to suitability under Alternative A for trout at all
25 locations, but would be slightly higher compared to Alternative A for warmwater nonnative fish
26 at the locations farthest downstream. TMFs would be tested under this alternative and would be
27 implemented for the entire LTEMP period if they were deemed successful at limiting rainbow
28 trout recruitment in the Glen Canyon reach. Based on modeling for Alternative E, it is
29 anticipated that TMFs would be triggered in about 3 out of 20 years, on average.
30

31 Alternative E has more HFEs (average of 17.1 HFEs and a maximum of 30 HFEs over
32 the 20-year LTEMP period) than either Alternative A or Alternative B, but fewer than the other
33 alternatives. This greater number of HFEs is expected to result in relatively high rainbow trout
34 abundance and emigration rates (see discussion of effects of HFEs in Section 4.5.2.2), although
35 the greater levels of within-day fluctuations and the implementation of TMFs are expected to
36 result in an overall reduction in age-1 and older fish (Figure 4.5-1), but slightly higher levels of
37 emigration (about 38,000 fish/yr) compared to Alternative A (see discussion of effects of
38 removal actions in Section 4.5.2.2). Slightly more large rainbow trout are expected (on average
39 about 830 fish) than under Alternative A based on modeling results (Figure 4.5-3).
40

41 **Impacts of Alternative E on Native Fish**

42

43
44 Under Alternative E, habitat quality and stability for native fish would be slightly lower
45 due to increased levels of within-day fluctuations during most months compared to
46 Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes

1 (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), is expected to differ
2 little from suitability and growth predicted for Alternative A.
3

4 Alternative E allows no spring HFEs for the first 10 years, but it has relatively similar
5 numbers of fall HFEs compared to Alternatives C, D, F, and G. The relatively high number of
6 HFEs under Alternative E would be expected to increase the abundance of trout and the number
7 of emigrants to the Little Colorado River reach (see discussion of effects of HFEs on nonnative
8 fish in Section 4.5.2.2) with potential adverse effects on humpback chub. The potential for
9 competition with and predation on humpback chub is expected to be partially controlled by
10 mechanical removal of trout in the Little Colorado River reach (see discussion of effects of
11 removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the
12 Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to
13 ongoing emigration from areas upstream in Marble Canyon. The modeled average minimum
14 number of adult humpback chub under Alternative E (about 5,300 fish) was about 6% higher
15 than under Alternative A (about 5,000 fish) (Figure 4.5-8), reflecting the combined effects on
16 growth and survival of humpback chub associated with slightly higher emigration rates for trout
17 from the Glen Canyon reach, slightly warmer mainstem temperatures at the confluence with the
18 Little Colorado River, and implementation of mechanical removal of trout in the Little Colorado
19 River reach when triggering criteria are met. The estimated absolute minimum number of adult
20 humpback chub over the 20-year LTEMP period under Alternative E is about 1,600. While
21 indirect benefits of TMFs to native fish as a result of reduced competition and predation by
22 rainbow trout are expected under this alternative, an unknown number of native fish would also
23 suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in
24 Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented
25 to assess effectiveness of the action, as well as the detrimental impacts on native fish and other
26 resources.
27
28

29 **Summary of Alternative E Impacts**

30

31 Under Alternative E, relatively even monthly release volumes would increase aquatic
32 food base productivity, but this increase could be offset by increased daily fluctuations. The
33 number of HFEs under Alternative E would favor midge and blackfly production, though the
34 number of HFEs would be less than under Alternative C. Temperature impacts on the aquatic
35 food base for Alternative E would be similar to those under Alternative C.
36

37 Under Alternative E, habitat quality and stability for nonnative and native fish would be
38 slightly lower than under Alternative A due to increased levels of within-day fluctuations during
39 most months. Stranding of YOY rainbow trout may also be slightly higher than under
40 Alternative A. Temperature suitability for trout, native fish, and growth of YOY humpback chub
41 under Alternative E would be similar to that under Alternative A; but would be slightly higher
42 for other warmwater nonnative fish species at locations farthest downstream from Glen Canyon
43 Dam. The high number of HFEs under Alternative E is expected to result in relatively high
44 rainbow trout abundance and emigration rates compared to Alternative A; although the greater
45 levels of within-day fluctuations and the implementation of TMFs are expected to result in an
46 overall reduction in age-1 and older fish but slightly higher levels of emigration compared to

1 Alternative A. Slightly more large rainbow trout (830) are expected than under Alternative A
2 (770). The modeled average minimum number of adult humpback chub under Alternative E
3 (about 5,300 fish) is slightly higher than under Alternative A (about 5,000 fish). The estimated
4 absolute minimum number of adult humpback chub over the 20-year LTEMP period under
5 Alternative E is about 1,600 compared to 1,500 under Alternative A.
6
7

8 **4.5.3.6 Alternative F**

9

10 **Impacts of Alternative F on Aquatic Food Base**

11

12
13 Compared to all other alternatives, Alternative F would have lower flow volumes, and
14 therefore potentially less benthic biomass, from July through the following March. Seasonally
15 adjusted steady flows would minimize the adverse effects of desiccation and dewatering that
16 occurs in a varial zone (Reclamation et al. 2002). Flow stabilization may allow for very high
17 snail densities, especially for the New Zealand mudsnail (Reclamation et al. 2002). In addition,
18 reduced drift rates occur under mildly fluctuating or steady flows (Shannon et al. 1996;
19 Rogers et al. 2003). Lower benthic productivity may also cause decreased drift over the long
20 term (Kennedy, Yackulic et al. 2014). Higher volumes in April through June may increase
21 benthic biomass compared to Alternative A, and would somewhat mimic pre-dam conditions
22 with increased flows during spring and early summer. Increased benthic productivity during this
23 period may also increase drift (Kennedy, Yackulic et al. 2014).
24

25 Under Alternative F, the 24-hr, 45,000-cfs high flows in early May in years without
26 sediment-triggered spring HFES, together with the May and June period of sustained high flows
27 and the week-long 25,000 cfs release at the end of June, would scour the benthos, particularly
28 within the Glen Canyon reach. This could improve the aquatic food base by reworking sediments
29 and removing fines that can limit production of benthic organisms. Alternative F would have an
30 average of 38.1 HFES (maximum of 40 HFES) (Table 4.2-1). The frequent HFES will favor
31 blackfly and midge production. Sustained high flows and HFES would also decrease the density
32 of New Zealand mudsnails.
33

34 No trout management actions would occur under Alternative F, but the rapid drop from
35 high flows in June to low flows in July could have similar effects to those of TMFs. If these flow
36 changes did not mimic the effects of TMFs, there would be continued competition for aquatic
37 food base resources between trout and other fish species.
38

39 The warmer mean monthly water temperatures under Alternative F at RM 225 may
40 slightly increase benthic production compared to all other alternatives, as modeled monthly
41 summer temperatures would range from 18.6 to 20.5°C (65.5 to 68.9°F) for July through August.
42 In addition to favoring adnate diatoms over stalked diatoms, these warmer temperatures would
43 tend to favor *Oscillatoria* over *Cladophora*. These changes would be considered detrimental to
44 the aquatic food base (Section 4.5.2.1). Otherwise, temperature impacts on the aquatic food base
45 would be similar to those described for Alternative A (Section 4.5.3.1).
46

1 **Impacts of Alternative F on Nonnative Fish**
2

3 Because there would be no within-day flow fluctuations, Alternative F is expected to
4 have positive effects on nonnative fish and their habitats by providing a greater level of habitat
5 stability than would occur under any of the non-steady flow alternatives. Although the results of
6 the temperature suitability modeling show only small differences among the alternatives in
7 overall suitability for trout, temperature suitability under Alternative F would be slightly greater,
8 compared to Alternative A, at RM 61 and slightly lower at RM 157 and RM 225 (Figure 4.5-4).
9 For warmwater nonnative fish, mainstem temperature suitability is expected to improve slightly,
10 compared to Alternative A, at RM 61 and RM 157 (Figure 4.5-5). The warmer temperatures at
11 the downstream locations during summer and fall months may slightly increase the potential for
12 successful reproduction, survival, and growth of warmwater nonnative fish compared to
13 Alternative A.
14

15 Among all alternatives, Alternative F has the greatest average modeled population size of
16 age-1 and older rainbow trout (about 160,000 fish) in the Glen Canyon reach (Figure 4.5-1), and
17 the greatest average annual number of rainbow trout (about 72,000 fish/yr) emigrating from the
18 Glen Canyon reach. These numbers reflect the more stable habitat conditions and very high
19 number of HFEs (an average of 39 HFEs and a maximum of 40 HFEs over the 20-year LTEMP
20 period) of this alternative that are expected to result in increased production and survival of YOY
21 rainbow trout (see discussion of effects of HFEs in Section 4.5.2.2). Because this alternative does
22 not include implementation of TMFs or mechanical removal, there is no offset to conditions that
23 would be likely to increase recruitment, resulting in larger numbers but lower growth rates for
24 trout in the Glen Canyon reach. There are expected to be, on average, fewer large rainbow trout
25 (about 590 fish) under this alternative than under any of the other alternatives (Figure 4.5-3). The
26 modeled results for Alternative F are consistent with results from an experiment conducted
27 during the spring and summer of 2000 to examine effects of low summer steady flows
28 (Ralston 2011). During that study, the abundance of some nonnative fish species (e.g., fathead
29 minnow, plains killifish, and rainbow trout) increased following periods with reduced
30 fluctuations and/or warmer water temperatures (Ralston 2011).
31
32

33 **Impacts of Alternative F on Native Fish**
34

35 Under Alternative F, there would be no within-day fluctuations in flow, resulting in a
36 high degree of nearshore habitat stability. The 24-hr, 45,000-cfs peak flow in May, extended
37 high flows of 20,000 cfs in May and June, and 7-day 25,000-cfs high flow at the end of June may
38 improve forage for native fish by reworking sediments and removing fines that can limit
39 production of benthic organisms. Compared to Alternative A, temperature suitability would be
40 slightly higher at RM 61 and lower at RM 213. Temperature suitability for native fish would be
41 lower at RM 225 (Diamond Creek) compared to other alternatives (Figure 4.5-9). Under
42 Alternative F, modeling estimated that YOY humpback chub would achieve a total length of
43 about 26 mm by the end of their first year at RM 61, and about 54 mm at RM 213 if rearing
44 occurred in main channel habitats; this level of growth is slightly higher than that estimated for
45 all other alternatives (Figure 4.5-7).
46

1 The minimum number of adult humpback chub under Alternative F (about 4,400 adult
2 fish) was estimated to be lower than under any of the other alternatives (Figure 4.5-8). This
3 lower estimated population size results from the high number of HFEs, low summer flows, and
4 lack of within-day fluctuations that promote production of rainbow trout in the Glen Canyon
5 reach and subsequent high emigration to the Marble Canyon reach (see Section 4.5.3.2), as well
6 as the lack of TMFs or mechanical removal that could offset increases in trout. The estimated
7 absolute minimum number of adult humpback chub over the 20-year LTEMP period under
8 Alternative F is about 1,400.

9
10 Historically, there have been few opportunities to study the effects of steady-flow
11 operations on fish resources downstream of Glen Canyon Dam, especially the effects of long-
12 term steady flow operations. During the spring and summer of 2000, a series of steady
13 discharges of water from Glen Canyon Dam were used to evaluate effects of aquatic habitat
14 stability and water temperatures on native fish growth and survival, with a particular focus on the
15 humpback chub (Ralston 2011). The hydrograph implemented for the experiment achieved
16 steady discharges at various levels that lasted for periods of 4 days to 8 weeks. The steady flows
17 did not appear to result in increased growth rates by humpback chub or other native fish,
18 although there was some evidence that nonnative fish species that could compete with or prey
19 upon native fish species (fathead minnow, plains killifish, and rainbow trout) experienced
20 population increases associated with reduced fluctuations and/or warmer water temperatures that
21 occurred during the experimental period (Ralston 2011). However, the short-term nature of the
22 experiment makes it difficult to draw conclusions about what effects a multi-year steady flow
23 operation would have.

24 25 26 **Summary of Alternative F Impacts**

27
28 Under Alternative F, food base biomass from July through the following March would be
29 potentially less compared to all other alternatives due to comparatively lower flow volumes.
30 Flow stabilization may allow for high benthic densities of New Zealand mudsnails, while
31 reduced benthic productivity is expected to reduce drift. Higher flow volumes in April through
32 June may increase benthic food base biomass and drift compared to Alternative A. The frequent
33 HFEs will favor blackfly and midge production. The warmer water temperatures for August and
34 September at RM 225 under Alternative F may slightly increase food base production even more
35 than Alternative D, although this could similarly be offset by change in diatoms from stalked to
36 adnate forms and favoring *Oscillatoria* over *Cladophora*.

37
38 Alternative F is expected to have positive effects on nonnative and native fish and their
39 habitats by providing a greater level of habitat stability than would occur under any of the non-
40 steady flow alternatives. Temperature suitability for nonnative and native fish under
41 Alternative F would be slightly higher than Alternative A at RM 61 and slightly lower at sites
42 further downstream. The warmer temperatures at the downstream locations during summer and
43 fall months may slightly increase the potential for successful reproduction, survival, and growth
44 of warmwater nonnative fish compared to Alternative A. Among all alternatives, Alternative F
45 has the greatest average modeled population size of age-1 and older rainbow trout (about
46 160,000 fish) in the Glen Canyon reach, and the greatest average annual number of rainbow trout

1 (about 72,000 fish/yr) emigrating from the Glen Canyon reach. There are expected to be, on
2 average, fewer large rainbow trout (about 590 fish) under this alternative than under any of the
3 other alternatives. The minimum number of adult humpback chub under Alternative F (about
4 4,400 adult fish) was estimated to be lower than under any of the other alternatives. The
5 estimated absolute minimum number of adult humpback chub under Alternative F is
6 about 1,400.

9 **4.5.3.7 Alternative G**

12 **Impacts of Alternative G on Aquatic Food Base**

14 Under Alternative G, changes in monthly release volumes would be limited only to those
15 necessary to adjust to changes in runoff forecasts. The benthic community would benefit from
16 these even monthly volumes and the steady within-day flows of this alternative. This would
17 allow somewhat consistent and stable aquatic food base conditions to persist throughout the year.
18 In addition, benthic community biomass would probably be greater under Alternative G
19 compared to Alternative F, because flows from July through the following February would be
20 higher under Alternative G. However, the year-round stable conditions may favor dominance by
21 less-desirable species such as the New Zealand mudsnail. Increased benthic production could
22 result in long-term increases in drift (Kennedy, Yackulic et al. 2014).

24 Alternative G would have an average of 24.5 HFEs (maximum of 40 HFEs)
25 (Table 4.2-1). The frequent HFEs are expected to favor blackfly and midge production. HFEs
26 would also decrease the density of New Zealand mudsnails. Impacts on the aquatic food base
27 from proactive spring HFEs would be similar to those under Alternative C (Section 4.5.3.3).

29 Under Alternative G, there could be fall HFEs of up to 45,000 cfs that could last as long
30 as 336 hr. These extended-duration HFEs would be of higher magnitude and could produce more
31 benthic scouring than the extended-duration HFEs for Alternative C. Drift from an extended fall
32 HFE may be elevated due to increased biomass of benthic invertebrates that may develop over
33 the summer months. HFEs longer than 96 hr may help to control the abundance of New Zealand
34 mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance.

36 The 4 to 5 months between a fall and spring HFE could preclude full recovery of most
37 benthic invertebrate assemblages. A spring HFE following a fall HFE, particularly a long-
38 duration HFE, could scour the remaining primary producers and susceptible invertebrates and
39 further delay the recovery of the aquatic food base. For this reason, implementation of a spring
40 HFE in years that follow an extended-duration fall HFE would be carefully considered.

1 Trout removal, as would occur under Alternative E, could indirectly increase the
2 availability of invertebrates to native fish by reducing the number of trout near the confluence of
3 the Little Colorado River (RM 61), thereby reducing competition for food resources. Under
4 Alternative G, TMFs would be tested and implemented, if tests are successful. TMFs could cause
5 short-term increases in drift rates and slightly decrease primary production.
6

7 Temperature impacts on the aquatic food base for Alternative G would be similar to those
8 under Alternative C (Section 4.5.3.3).
9

10 **Impacts of Alternative G on Nonnative Fish**

11 Under Alternative G, there would be no within-day fluctuations, and monthly volumes
12 would only vary as a result of changes in runoff forecasts. As a result, habitat stability would be
13 greater under this alternative than under any of other alternatives. Under this alternative, trout
14 would continue to be supported in the upper reaches of the river below Glen Canyon Dam, while
15 warmwater nonnative species would continue to occur in the lower portions of the river and
16 tributaries. Similar to Alternative F, improved temperature suitability in the lower reaches of the
17 river could increase the potential for successful spawning of warmwater nonnative fishes in
18 nearshore main channel habitats. TMFs would be tested under this alternative and would be
19 implemented for the entire LTEMP period if they were deemed successful at limiting rainbow
20 trout recruitment in the Glen Canyon reach. Based on modeling for Alternative G, it is
21 anticipated that TMFs would be triggered in about 11 out of 20 years, on average.
22
23
24

25 The annual population size of rainbow trout in the Glen Canyon reach is expected to be
26 higher under Alternative G than under any of the non-steady flow alternatives, and only slightly
27 less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively). Similarly, the
28 estimated annual number of rainbow trout emigrating from the Glen Canyon reach to the Marble
29 Canyon reach is greater than under any of the non-steady flow alternatives, and second only to
30 Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). The relatively high
31 abundance and emigration rate reflect, in part, the high number of HFEs that could occur with
32 this alternative (an average of 24.5 HFEs and a maximum of 40 HFEs over the 20-year LTEMP
33 period), including sediment-triggered and proactive spring HFEs, which may strongly favor trout
34 recruitment, and the absence of within-day fluctuations. However, TMFs and mechanical
35 removal of trout, which are included as operational elements in this alternative, are expected to
36 partially mitigate the increased trout production. Alternative G would have the second-lowest
37 average number of large rainbow trout (about 690 fish >16 in. total length) (Figure 4.5-3). The
38 modeled results for nonnative fish under Alternative G are consistent with results from an
39 experiment conducted during the spring and summer of 2000 to examine effects of low summer
40 steady flows (Ralston 2011). During that study, the abundance of some nonnative fish species
41 (e.g., fathead minnow, plains killifish, and rainbow trout) increased following periods with
42 reduced fluctuations and/or warmer water temperatures (Ralston 2011). However, the short-term
43 nature of the experiment that was conducted makes it difficult to draw conclusions about what
44 effects a multi-year steady flow operation would have.
45

Impacts of Alternative G on Native Fish

Under Alternative G, habitat stability for native fish would be greater than under any of the other alternatives. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ little from suitability and growth predicted for Alternative A.

The high number of HFEs under Alternative G is expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach, with potential adverse effects on humpback chub. The potential for competition with and predation of humpback chub are expected to be partially offset by mechanical removal (when triggering criteria are met) of trout in the Little Colorado River reach. However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. Modeling indicated that the average minimum number of adult humpback chub (about 4,700 adult fish) under Alternative G would be the second lowest value of all alternatives and would be approximately 6% lower than under Alternative A (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative G is about 1,700. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources. For information regarding past studies of the effects of steady-flow operations on native fish downstream of Glen Canyon Dam, refer to Section 4.5.3.6.

Summary of Alternative G Impacts

Under Alternative G, somewhat consistent and stable aquatic food base conditions to persist throughout the year. Benthic food base biomass and drift would probably be greater under Alternative G compared to Alternative F, because flows from July through the following February would be higher. However, stable flows may favor dominance by the New Zealand mudsnail. Potentially higher drift rates from spring flows under Alternative F would not occur under Alternative G. The frequent HFEs are expected to favor blackfly and midge production. Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternative C.

Habitat stability for nonnative and native fish would be greater under Alternative G than under any of the other alternatives. Similar to Alternative F, improved temperature suitability in the lower reaches of the river could increase the potential for successful spawning of warmwater nonnative fishes in nearshore main channel habitats; whereas, temperature suitability for native fishes, as well as growth of YOY humpback chub, are expected to differ little from Alternative A. The annual population size of rainbow trout in the Glen Canyon reach is expected to be higher under Alternative G than under any of the non-steady flow alternatives, and only slightly less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively).

1 Similarly, the estimated annual number of rainbow trout emigrating from the Glen Canyon reach
2 to the Marble Canyon reach is greater than under any of the non-steady flow alternatives, and
3 second only to Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). Alternative G
4 would have the second-lowest average number of large rainbow trout (about 690 fish >16 in.
5 total length). The average minimum number of adult humpback chub (about 4,700 adult fish)
6 under Alternative G would be the second lowest value of all alternatives. The estimated absolute
7 minimum number of adult humpback chub under Alternative G is about 1,700.
8
9

10 4.6 VEGETATION

11
12 This section presents an evaluation of the impacts of the LTEMP on riparian vegetation
13 of the Colorado River corridor between Glen Canyon Dam and Lake Mead. Glen Canyon Dam
14 operations affect river flow and stage, which in turn affect the disturbance regime, soil moisture,
15 and ultimately the distribution of vegetation species and communities in the river corridor. In
16 addition to the effects of operations on vegetation communities, the effects on vegetation of non-
17 flow actions were evaluated, including vegetation restoration activities. Analysis methods, a
18 summary of anticipated impacts, and alternative specific impacts are presented.
19
20

21 4.6.1 Analysis Methods

22
23 Three sources of information were
24 evaluated in order to analyze the impacts of the
25 alternatives on plant communities. First,
26 information found in studies on vegetation done
27 to date was examined. Secondly, a model based
28 on published studies and collected data was used
29 to predict potential effects. Third, the combined
30 information from the studies and model was
31 evaluated to analyze the potential effects of the
32 alternatives over the period of the LTEMP. The
33 studies allowed an assessment of effects that go
34 beyond the limitations of the model.
35

36 The model enabled an evaluation of
37 effects by predicting four characteristics of
38 vegetation. The metrics that reflect these
39 characteristics were calculated using the results
40 of an existing model for Colorado River riparian
41 vegetation downstream of the Paria River
42 (Ralston et al. 2014). Seven vegetation states
43 were used in the model to represent plant
44 community types found along the river on
45 sandbars and channel margins in the New High

Issue: How do alternatives affect riparian
vegetation in the project area?

Impact Indicators:

- Change in the composition of plant communities in the Old High Water Zone
- Changes in habitat of special status plant species
- Changes in cover of wetland community types
- Changes in the composition of the New High Water Zone and wetland vegetation as indicated by four metrics: (1) change in cover of native community types; (2) change in diversity of native community types; (3) change in the ratio of native to nonnative community types; and (4) change in the arrowweed community type

1 Water Zone and Fluctuation Zone (Section 3.6). Species associated with a particular state
2 respond similarly to Colorado River hydrologic factors such as depth, timing, and duration of
3 inundation. These states and the plant species associated with each are given in Table 4.6-1. The
4 model and data used for the calculation of performance metrics are based on vegetation studies
5 conducted within GCNP (see citations in Ralston et al. 2014) and was not used to assess changes
6 to riparian vegetation communities within Glen Canyon. Although the model is a simplification
7 of the complexities of the riparian ecosystem, it is a valuable tool for assessing potential changes
8 in riparian vegetation under a variety of flow regimes. Model details are described in
9 Ralston et al. (2014). The four metrics are:

- 11 1. Relative change in cover of native-dominated vegetation community types
12 (other than arrowweed) on sandbars and channel margins using the total
13 percentage increase in native states (change in native cover =
14 $\text{cover}_{\text{final}}/\text{cover}_{\text{initial}}$; a result >1 is a beneficial change).
- 16 2. Relative change in diversity of native vegetation community types (other than
17 arrowweed) on sandbars and channel margins using the Shannon Weiner
18 index for richness/evenness (change in diversity = $\text{diversity}_{\text{final}}/\text{diversity}_{\text{initial}}$; a
19 result >1 is a beneficial change).
- 21 3. Relative change in the ratio of native- (other than arrowweed) to nonnative-
22 dominated vegetation community types on sandbars and channel margins
23 (change in native/nonnative ratio = $\text{ratio}_{\text{final}}/\text{ratio}_{\text{initial}}$; a result >1 is a
24 beneficial change).
- 26 4. Relative change in the arrowweed community type on sandbars and channel
27 margins using the total percentage decrease in the arrowweed state (change in
28 arrowweed = $\text{arrowweed}_{\text{initial}}/\text{arrowweed}_{\text{final}}$; a result >1 is a beneficial
29 change). Because the desired change is a decrease in arrowweed, this metric is
30 calculated as initial/final, unlike the other metrics.

32 These performance metrics were developed from the resource goal for riparian vegetation
33 downstream of Glen Canyon Dam: *Maintain native vegetation and wildlife habitat in various*
34 *stages of maturity that are diverse, healthy, productive, self-sustaining, and ecologically*
35 *appropriate.*

37 The vegetation model has several limitations that should be noted when considering the
38 modeling results. The model was designed as a conceptual as opposed to a predictive model;
39 therefore, the results are used in this analysis carefully and in combination with the literature
40 because the model is a simplification with limitations in the ability to assess on-the-ground
41 changes. However, it is the best available tool for impact analysis, when used in conjunction with
42 field studies and literature.

44 Several issues that could not be addressed by the model are discussed qualitatively or
45 quantitatively based on literature from field studies in this section below. These include the
46 dynamics of the tamarisk leaf beetle (*Diorhabda* spp.) on tamarisk distribution and abundance;

1 **TABLE 4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels**

Vegetation States	Primary Plant Species	Additional Species	Submodel/Landform
Bare Sand	<1% vegetation cover		All submodels
Common Reed Temperate Herbaceous Vegetation (Marsh)	Common reed (<i>Phragmites australis</i>), cattail (<i>Typha</i> <i>domingensis</i> , <i>T. latifolia</i>)	Common tule (<i>Schoenoplectus</i> <i>acutus</i>), creeping bent grass (<i>Polypogon viridis</i>)	Lower Reattachment Bar
Coyote Willow-Emory Seep Willow Shrubland/ Horsetail Herbaceous Vegetation (Shrub Wetland)	Horsetail (<i>Equisetum</i> <i>laevigatum</i>), coyote willow (<i>Salix exigua</i>), <i>Baccharis emoryi</i> , <i>Schoenoplectus pungens</i>	<i>Eleocharis palustris</i> , <i>Muhlenbergia asperifolia</i>	Lower Channel Margin, Lower Reattachment Bar
Tamarisk Temporarily Flooded Shrubland	Tamarisk (<i>Tamarix</i> spp.)		All submodels
Cottonwood/Coyote Willow Forest ^a (Cottonwood-willow)	Coyote willow, cottonwood (<i>Populus</i> <i>fremontii</i>)	<i>Salix gooddingii</i> , <i>Baccharis</i> <i>salicifolia</i> , <i>Distichlis spicata</i> , <i>Muhlenbergia asperifolia</i> , <i>Phragmites australis</i> , <i>Equisetum</i> <i>spp.</i> , <i>Juncus</i> spp., <i>Carex</i> spp., <i>Elaeagnus angustifolia</i> , <i>Tamarix</i> <i>spp.</i> , <i>Agrostis stolonifera</i> , <i>Melilotus</i> spp.	Lower Channel Margin, Lower Separation Bar
Arrowweed Seasonally Flooded Shrubland (Arrowweed)	Arrowweed (<i>Pluchea</i> <i>sericea</i>)	<i>Baccharis</i> spp., mesquite (<i>Prosopis glandulosa</i>), coyote willow	Lower Reattachment Bar, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin
Mesquite Shrubland (Mesquite)	Mesquite (<i>Prosopis</i> <i>glandulosa</i> var. <i>torreyana</i>)	<i>Baccharis</i> spp., <i>Pluchea sericea</i>	Lower Channel Margin, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin

^a Although an element of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

Source: Ralston et al. (2014).

2
3

1 the overall decrease in area of the Old High Water Zone and the mortality of species within that
2 zone; the increase or decrease of open sand that could not be captured in this model, as it could
3 not be coupled with the sediment models; the effects from NPS's experimental vegetation
4 restoration program (common to all alternatives); and the fact that the model considers
5 hypothetical sandbars and was not spatially explicit in relation to current and potential future
6 conditions.

7
8 The vegetation model was developed to compare the effects of various flow regimes on
9 Colorado River riparian vegetation. The model consists of six geomorphic submodels based on
10 landforms that are known to influence vegetation floristics and structure: Lower Separation Bar,
11 Upper Separation Bar, Lower Reattachment Bar, Upper Reattachment Bar, Lower Channel
12 Margin, and Upper Channel Margin. The upper and lower landform surfaces are separated at the
13 25,000-cfs stage elevation (see Section 3.3.1.1 for a description of these landforms).

14
15 The four vegetation states dominated by native plant species are marsh (Common Reed
16 Temperate Herbaceous Vegetation), shrub wetland (Coyote Willow-Emory Seep Willow
17 Shrubland/Horsetail Herbaceous Vegetation), cottonwood-willow (Cottonwood/Coyote Willow
18 Forest), and mesquite (Mesquite Shrubland). Although arrowweed is a native species, prior to the
19 dam's construction, it was strongly controlled by spring flooding and was not common, but with
20 cessation of spring floods it has invaded many sandbars and formed monocultures. Because of
21 this tendency to form monocultures under these conditions, arrowweed (Arrowweed Seasonally
22 Flooded Shrubland) states are excluded from the desired native states in the metrics. One
23 nonnative state, tamarisk (Tamarisk Temporarily Flooded Shrubland), is included in the model.
24 Bare Sand is also included as one of the possible states in the model. As described in Section 3.6,
25 a number of other plant community types also occur within the riparian area downstream of Glen
26 Canyon Dam (see also Table H-3). These plant community types vary somewhat by river reach,
27 in the Old High Water Zone, New High Water Zone, and Fluctuation Zone.

28
29 In the model, the magnitude and timing of various important hydrologic events were
30 identified for each model run and evaluated for the potential effects on vegetation (see Table G-2
31 in Appendix G for a listing and description of these hydrologic events). The model uses the daily
32 maximum flow for the evaluation of each alternative. Important hydrologic events included spill
33 flows (>45,000 cfs), spring HFEs (>31,500 cfs to 45,000 cfs), fall HFEs (>31,500 cfs to
34 45,000 cfs), extended low flows (daily maximum \leq 10,000 cfs for at least 30 consecutive days),
35 extended high flows (daily maximum \geq 20,000 cfs for at least 30 consecutive days), and flows
36 that can fluctuate up to 25,000 cfs, (i.e., the absence of spill flows or extended high or extended
37 low flows). Although periodic spill flows (>45,000 cfs) could occur based on historic hydrologic
38 conditions within the 20-year period of this evaluation, these would likely be infrequent and
39 would occur at equal frequency under all alternatives. These spill flows are non-discretionary
40 emergency actions and are not part of the alternatives, but were part of the hydrologic modeling.
41 The timing of these events relative to the growing season (May–September) or non-growing
42 season (October–March) was also determined. Growing seasons vary depending on the reach,
43 but were generalized to these months for the model.

44
45 Daily fluctuation patterns generally produce the extended high and extended low flows.
46 For example, Alternative B, with relatively large fluctuations, has a higher frequency of daily

1 maxima $\geq 20,000$ cfs for at least 30 consecutive days, and therefore more extended high flows;
2 Alternatives F and G, two alternatives with no fluctuations, have a higher frequency of extended
3 low flows. Monthly release volumes also affect these events. Alternative C, for example, has
4 relatively small fluctuations but also low release volumes August through November, resulting in
5 a higher frequency of extended low flows than Alternative G.
6

7 The model predicts transitions from one state to another, based on a set of rules that
8 considers the frequency and duration of hydrologic events. The transition rules for the upper
9 portions of the bars and channel margin are the same because of the similarity of plant
10 community types and responses to flow characteristics. These transition rules are based on the
11 effects of scouring, drowning, desiccation, and sediment deposition on riparian plant species.
12 HFEs result in sediment deposition, but scouring is minor and limited to low-elevation wetland
13 species (Kearsley and Ayers 1999; Ralston 2010; Stevens et al. 2001). HFEs transport seeds of
14 nonnative as well as native species (Kennedy and Ralston 2011; Ralston 2011; Spence 1996).
15 Repeated extended high flows (i.e., flows with daily maximum $\geq 20,000$ cfs for at least
16 30 consecutive days) result in removal of vegetation by drowning and scouring, primarily on
17 lower elevation surfaces (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010).
18 Increased soil moisture at upper elevations from extended high flows can increase vegetation
19 growth and seedling establishment (Waring 1995; Sher et al. 2000; Mortenson et al. 2012). The
20 germination of seeds transported by HFEs or extended high flows is promoted by extended low
21 flows (e.g., elevated base flows) that reduce disturbance, expose lower elevation surfaces, and
22 maintain soil moisture at lower elevations, all of which are conducive to seedling growth
23 (Porter 2002; Ralston 2011). Extended low flows (i.e., flows with daily maximum $\leq 10,000$ cfs
24 for at least 30 consecutive days) also can result in the lowering of groundwater levels, thus
25 increasing the depth to groundwater and the reduction of soil moisture, creating conditions that
26 favor the growth of more drought-tolerant species (Porter 2002; Stevens et al. 1995).
27

28 Model results include the total number of years each state occurs for the 20-year period
29 of the model run according to each potential starting state in each submodel. For example, the
30 reattachment bar submodel uses five different starting states for each hydrologic trace: bare sand,
31 marsh, shrub wetland, tamarisk, and arrowweed. Model results were used to calculate the metrics
32 for each alternative using the sum of each of the states for all six models. This value was then
33 compared to the number of years each state would have accumulated, if the current condition
34 was maintained, i.e., if no transitions occurred and each of the seven states remained the same for
35 the full 20 years of the model run. This proportion was multiplied by the acreage of mapped
36 cover types from the NPS Vegetation Map of GCNP (Kearsley et al. 2015) corresponding to the
37 seven model states in order to provide a sense of the relative spatial scale of potential changes
38 under each Alternative (Table 4.6-2). Because, as noted above, the model considers hypothetical
39 sandbars due to the very dynamic nature of sand deposition and erosion in the canyon, the model
40 cannot be used to accurately predict changes in total bare sand or riparian vegetation area, and
41 results should only be used to determine the relative contribution of vegetation states to total
42 area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a
43 sense of the overall scale of vegetation changes, but do not represent actual predicted changes in
44 area.
45

1 **TABLE 4.6-2 Vegetation States and Corresponding Mapped Vegetation Types**

Vegetation States	Mapped Vegetation Classes ^a	Area (ac)
Bare Sand	Unvegetated Surfaces and Built Up Areas	112
Marsh (Common Reed Temperate Herbaceous Vegetation)	<i>Phragmites australis</i> Western North America Temperate Semi-Natural Herbaceous Vegetation	4.4
Shrub Wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation)	Arid West Emergent Marsh	0.2
Tamarisk (Tamarisk Temporarily Flooded Shrubland)	<i>Tamarix</i> spp. Temporarily Flooded Semi-Natural Shrubland	273.7
Cottonwood-Willow (Cottonwood/Coyote Willow Forest ^b)	<i>Baccharis</i> spp.– <i>Salix exigua</i> – <i>Pluchea sericea</i> Shrubland Alliance	177.3
Arrowweed (Arrowweed Seasonally Flooded Shrubland)	<i>Baccharis</i> spp.– <i>Salix exigua</i> – <i>Pluchea sericea</i> Shrubland Alliance	177.3
Mesquite (Mesquite Shrubland)	<i>Prosopis glandulosa</i> var. <i>torreyana</i> Shrubland	137.1

^a Kearsley et al. (2015), which mapped RM 0-278; vegetation classes and area are based on 2007 and 2010 aerial photography and do not necessarily reflect current conditions. This mapping was limited to GCNP and did not include Glen Canyon.

^b Although a component of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

2
 3
 4 The results for the four metrics were then summed to derive a final score for each
 5 alternative. Alternatives with higher scores were considered to have come closer to achieving the
 6 resource goal. Several factors other than the operational characteristics considered by the models
 7 have a strong influence on the riparian vegetation below the dam, however, due to a lack of
 8 information on these potential effects and for the purposes of this analysis, it is assumed that
 9 these effects would apply equally across all alternatives. These include changes in precipitation,
 10 defoliation of tamarisk by the tamarisk leaf beetle and other insects, and experimental vegetation
 11 management activities implemented by the NPS to reduce invasive plant populations and
 12 increase local populations of desired native plants (Figure 4.6-1). The impacts of these factors
 13 were assessed in light of the potential vegetation changes shown by the state and transition
 14 model.

15

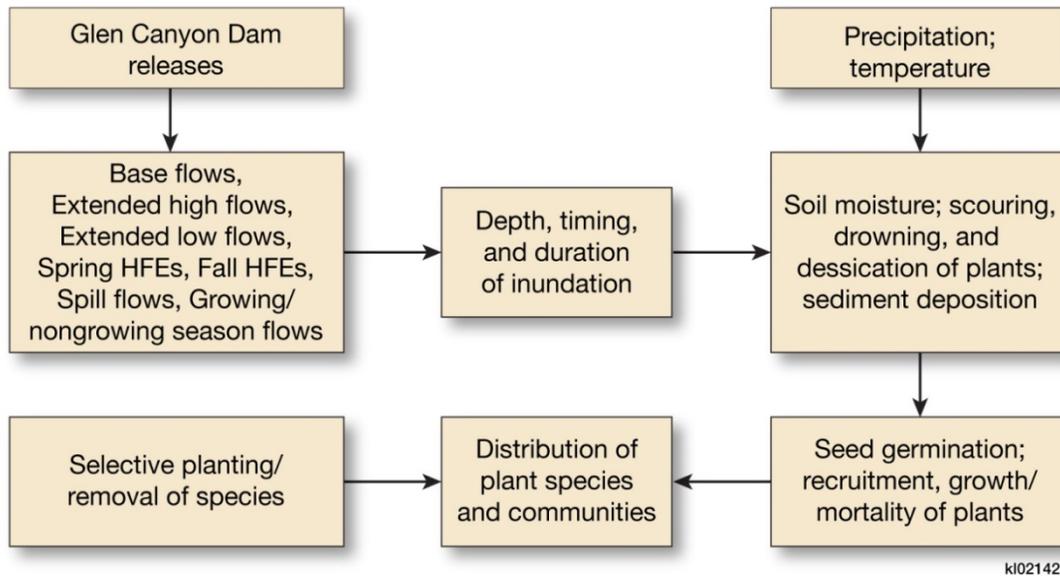


FIGURE 4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon Dam

4.6.2 Summary of Impacts

Impacts on plant communities of the Old High Water Zone, New High Water Zone, and wetlands for the 20-year LTEMP period are summarized below. Table 4.6-3 provides an overview of the anticipated impacts by alternative, as well as the important flow characteristics associated with the effects of each alternative. Figure 4.6-2 compares the predicted effects of each alternative on vegetation characteristics as measured using four metrics. A score of 1 indicates no change from initial conditions; values >1 indicate an improvement relative to current conditions (increase in native cover, native diversity, or native/nonnative diversity; decrease in arrowweed); values <1 indicate a decline relative to current conditions (decrease in native cover, native diversity, or native/nonnative ratio; increase in arrowweed), and Figure 4.6-3 presents the overall impacts under the LTEMP alternatives. In this case, a total score of 4.0 calculated by summing the scores for each of the 4 metrics under each alternative indicates no change from initial conditions; values >4 indicate an improvement relative to current conditions; and values <1 indicate a decline relative to current conditions. See Appendix G for additional details regarding the application of the vegetation model in the analysis of impacts.

4.6.2.1 Impacts on Old High Water Zone Vegetation

The riparian vegetation that became established along the Colorado River channel margin in response to annual peak flows prior to the construction of Glen Canyon Dam is located at high flow stage elevations (above 60,000 cfs, but primarily from about 100,000 to approximately 200,000 cfs), well above the level of current dam operations. The Old High Water Zone plant communities are described in Section 3.6. Mortality of riparian plants within this zone, along with a lack of seedling establishment for some species, such as mesquite and hackberry, have

1 **TABLE 4.6-3 Summary of Impacts on Old High-Water Zone, New High-Water Zone, and Wetland Plant Community Types**

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	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.	Similar to Alternative A (decline under hydropower improvement flows). Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, increase in arrowweed, increase in native diversity (decrease under hydropower improvement flows), and increase in native/nonnative ratio (decrease under hydropower improvement flows); decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio; decrease in arrowweed; decrease in wetland community cover; impacts on special status species.	Improvement from Alternative A. Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native/nonnative ratio, decrease in arrowweed and increase in native diversity; decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative); decrease in arrowweed; decrease in wetland community cover; impacts and potential benefit to special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio; decrease in arrowweed; decrease in wetland community cover; impacts on special status species.

4-158

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Old High Water Zone							
	Relative to current conditions, continued narrowing of zone due to lack of sufficiently high flows.	Same as Alternative A	Narrowing of zone as under Alternative A; more spring HFEs may result in greater survival of lower elevation plants.	Narrowing of zone as under Alternative A; more spring HFEs may result in greater survival of lower elevation plants.	Same as Alternative A	Narrowing of zone as under Alternative A; annual spring HFEs may result in greater survival of lower elevation plants.	Narrowing of zone as under Alternative A; more spring HFEs may result in greater survival of lower elevation plants.
New High Water Zone and Wetlands^a							
Relative change in cover of native vegetation community types	Relative to current conditions, 17% (55.2 ac ^a) overall decrease in native plant community cover over the LTEMP period, resulting from few spring HFEs, occasional fall HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows; 28% (1.3 ac) decrease in wetland community cover resulting from extended high flows.	Improvement from Alternative A; 15% (48.3 ac) overall decrease in native plant community cover, (47 % decrease under hydropower improvement flows) resulting from few spring HFEs, more fall HFEs, slightly more extended high flows; 20% (0.9 ac) decrease in wetland community cover (83% [3.8 ac] decrease under hydropower improvement flows) resulting from extended high flows.	Decline from Alternative A; 37% (117.7 ac) overall decrease in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 75% (3.4 ac) decrease in wetland community cover resulting from extended low flows and extended high flows.	Improvement from Alternative A; 12% (39.5 ac) overall decrease in native plant community cover, resulting from more HFEs, more seasons without extended high or low flows, frequent extended high flows; 16% (0.8 ac) decrease in wetland community cover resulting from extended high flows.	Decline from Alternative A 20% (63.5 ac) overall decrease in native plant community cover, resulting from more fall HFEs, slightly more growing-season extended low flows; 38% (1.7 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Decline from Alternative A 30% (95.0 ac) overall decrease in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 86% (4.0 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Decline from Alternative A 29% (93.7 ac) overall decrease in native plant community cover, resulting from more HFEs, more extended low flows, occasional extended high flows; 58% (2.6 ac) decrease in wetland community cover resulting from extended low flows and extended high flows.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>New High Water Zone and Wetlands^a (Cont.)</i>							
Relative change in diversity of native vegetation community types	Relative to current conditions, 2% decrease in native diversity over the LTEMP period due to decrease in wetland communities resulting from occasional growing-season extended low flows.	Improvement from Alternative A; 3% increase in native diversity, distribution of community types similar to initial condition (9% decrease under hydropower improvement flows).	Decline from Alternative A; 8% decrease in native diversity, decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.	Improvement from Alternative A; 2% increase in native diversity, distribution of community types similar to initial condition.	Decline from Alternative A; 2% decrease in native diversity, decrease in wetland communities resulting from slightly more growing-season extended low flows.	Decline from Alternative A; 9% decrease in native diversity, decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.	Decline from Alternative A; 3% decrease in native diversity, decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.
Relative change in the ratio of native- to nonnative-dominated vegetation community types	Potential benefit relative to current conditions; 5% increase in ratio, 58.4 ac decrease in tamarisk over the LTEMP period resulting from frequent extended high flows, few extended low flows, and spring HFES. Tamarisk leaf beetle and non-flow vegetation restoration activities may increase benefit.	Improvement from Alternative A; 15% increase in ratio (13% decrease under hydropower improvement flows), 71.4 ac decrease in tamarisk (107 ac decrease under hydropower improvement flows) resulting from few spring HFES, slightly more extended high flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may increase benefit.	Decline from Alternative A; 54% decrease in ratio, 104 ac increase in tamarisk resulting from more HFES, fewer seasons without extended high or low flows, more extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 5% decrease in ratio, 22.4 ac decrease in tamarisk resulting from extended high flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 4% decrease in ratio, 45.7 ac decrease in tamarisk resulting from more fall HFES, slightly more growing-season extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 62% decrease in ratio, 231 ac increase in tamarisk resulting from more HFES, fewer seasons without extended high or low flows, more extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 40% decrease in ratio, 46.4 ac increase in tamarisk resulting from more HFES, more extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.

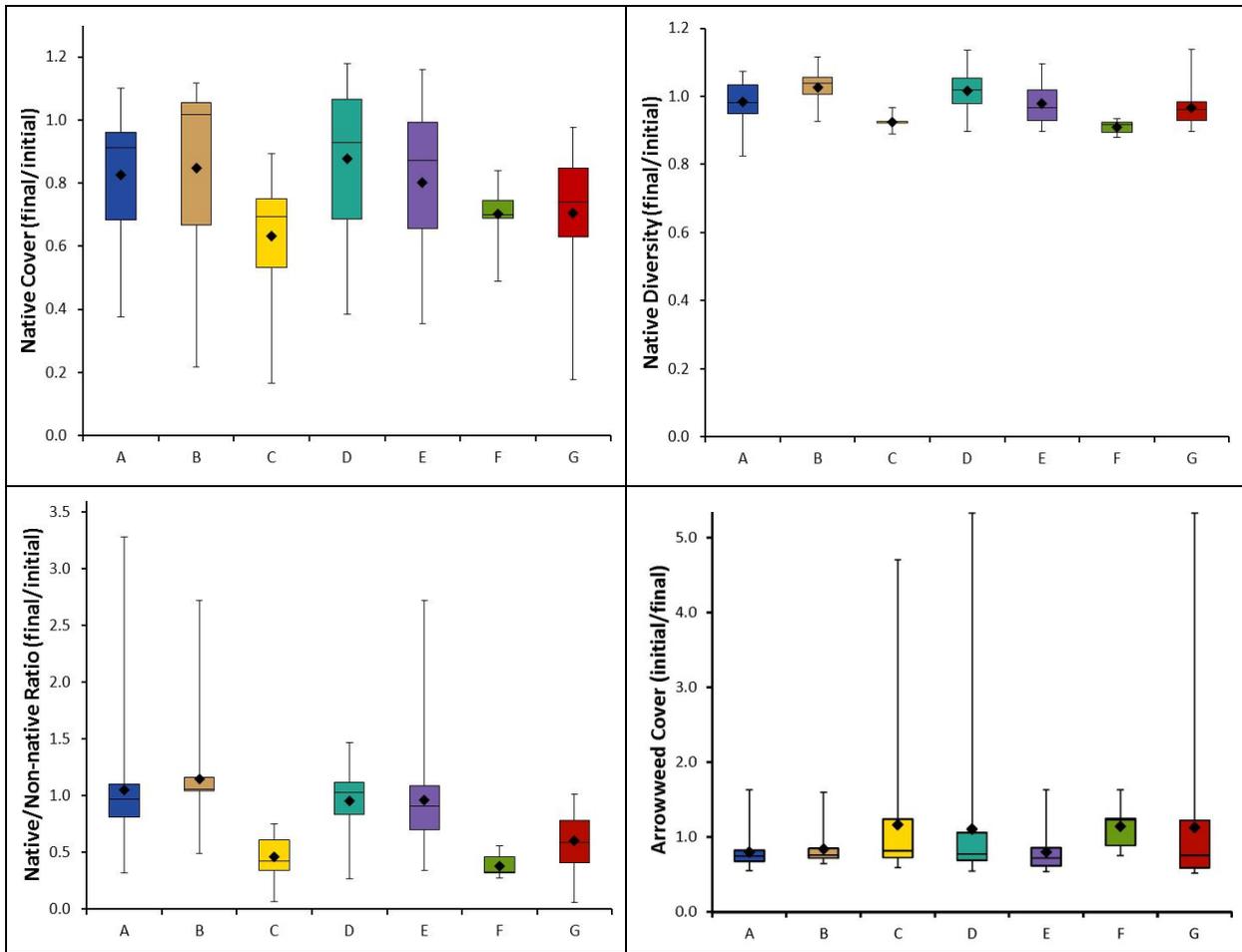
TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>New High Water Zone and Wetlands^a (Cont.)</i>							
Relative change in the arrowweed community type	Adverse impact; 25% (44.5 ac) increase in LTEMP period resulting from few spring HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows. Non-flow vegetation restoration activities may decrease adverse impact.	Improvement relative to Alternative A; 19% (33.3 ac) increase in arrowweed resulting from more extended high flows (24% increase under hydropower improvement flows). Non-flow vegetation restoration activities may decrease adverse impact.	Improvement relative to Alternative A; 14% (25.1 ac) decrease in arrowweed resulting from repeated extended low flows and extended high flows. Non-flow vegetation restoration activities may increase benefit.	Improvement relative to Alternative A; 10% (17.1 ac) decrease in arrowweed resulting from repeated extended high flows, frequent fall HFEs, and few growing season extended low flows. Non-flow vegetation restoration activities may increase benefit.	Similar to Alternative A; 25% (44.0 ac) increase in arrowweed resulting from more HFEs, more growing-season extended low flows, frequent growing-season extended high flows. Non-flow vegetation restoration activities may decrease adverse impact.	Improvement relative to Alternative A; 13% (22.2 ac) decrease in arrowweed resulting from more HFEs, repeated extended high flows. Non-flow vegetation restoration activities may increase benefit.	Improvement relative to Alternative A; 11% (20.1 ac) decrease in arrowweed resulting from more HFEs, growing-season extended low flows, fewer growing-season extended high flows. Non-flow vegetation restoration activities may increase benefit.
Special status plant species ^b	Adverse impact on wetland species from loss of habitat.	Similar to Alternative A. Adverse impact on wetland species from loss of habitat.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, wetland species from loss of habitat.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, wetland species from loss of habitat.	Similar to Alternative A. Adverse impact on wetland species from loss of habitat.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, Lake Mead shoreline species from high lake levels, wetland species from loss of habitat; potential benefit for inactive floodplain species from HFEs.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, wetland species from loss of habitat.

4-161

TABLE 4.6-3 (Cont.)

- ^a Changes in area are presented for each community type; however, because of the very dynamic nature of sand deposition and erosion in the canyon, the model cannot be used to accurately predict changes in total bare sand or riparian vegetation area and results should only be used to determine the relative contribution of vegetation states to total area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a sense of the overall scale of vegetation changes, but do not represent actual predicted changes in area.
- ^b Details regarding special status plant species are provided in Table 4.6-6.



1 **FIGURE 4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as Predicted**
 2 **by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the**
 3 **end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change**
 4 **over the LTEMP period; values >1 indicate an improvement relative to current conditions;**
 5 **values <1 indicate a decline relative to current conditions. Note that diamond = mean; horizontal**
 6 **line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower**
 7 **whisker = minimum; upper whisker = maximum.)**
 8
 9

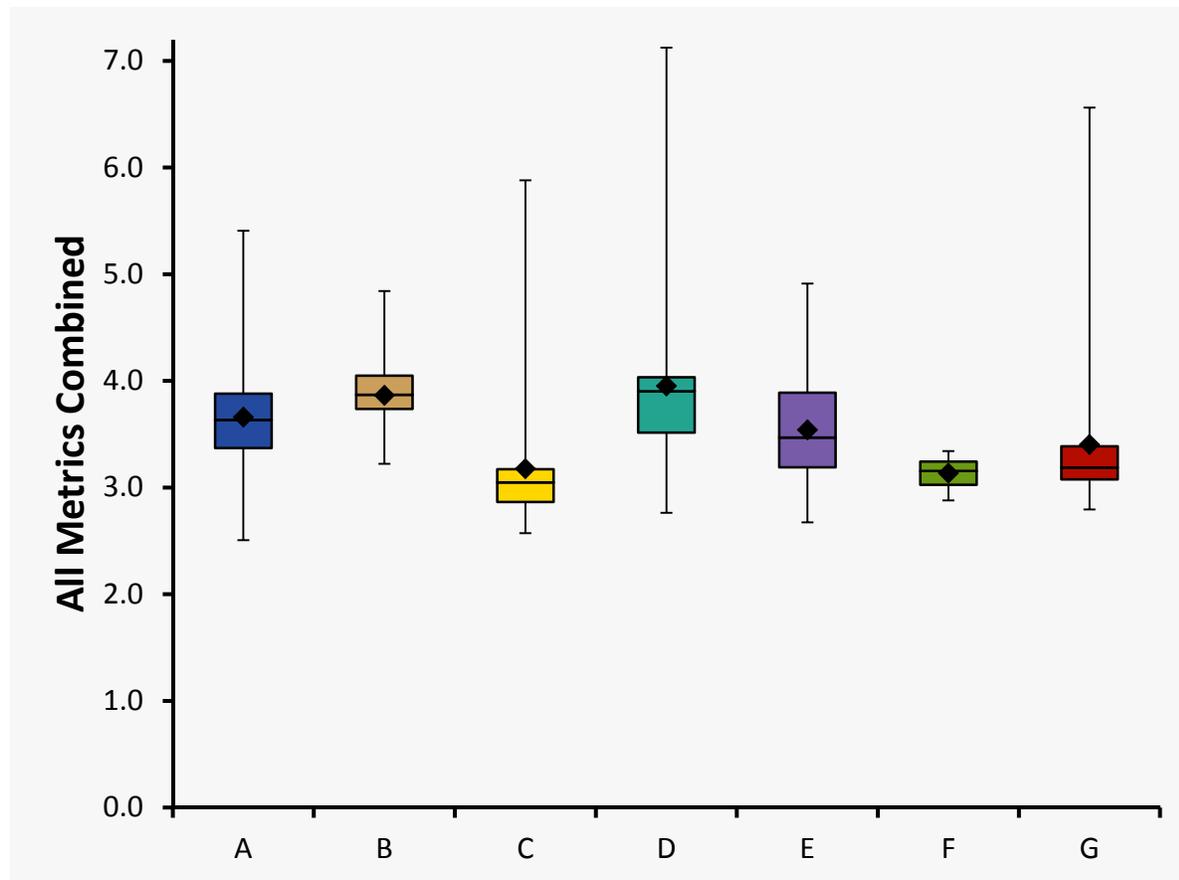


FIGURE 4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as Predicted by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the end of the LTEMP period relative to the amount at the beginning; values of 4 indicate no change over the LTEMP period; values >4 indicate an improvement relative to current conditions; values <4 indicate a decline relative to current conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

been occurring for decades, because of a lack of sufficiently high flows and nutrient-rich sediment (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Dam operations, other than HFEs, do not exceed 31,500 cfs flows (although all alternatives have a normal maximum operating flow of 25,000 cfs), and HFEs do not exceed 45,000 cfs. None of the alternatives considered would include flows sufficient to maintain these pre-dam plant communities. HFEs could provide soil moisture to the deep root systems of some Old High Water Zone plants, providing occasional soil moisture. Studies indicate that dam releases can affect water availability to plants at elevations up to approximately 15,000 cfs above flow levels (Melis et al. 2006; Ralston 2005). Alternatives with more frequent spring HFEs, such as Alternative F with annual spring HFEs, or Alternatives C, D, and G, all with considerably more spring HFEs than Alternative A (Section 4.2), may result in higher survival rates of plants

1 at lower elevations of the Old High Water Zone than Alternative A. Several alternatives include
2 extended-duration HFEs (longer than 96 hr; e.g., up to 250 hr under Alternative D); however, as
3 these HFEs only occur during the fall (the non-growing season), their contribution to higher
4 survival rates would likely be limited.

5
6 Because of generally continued low soil moisture and lack of recruitment opportunities
7 under all alternatives, the upper margins of this zone would be expected to continue moving
8 downslope, with a continued narrowing of the riparian zones. Desert species occurring on the
9 pre-dam flood terraces and windblown sand deposits above the Old High Water Zone would
10 increasingly establish within this zone, depending on climate and precipitation. Overall, all
11 alternatives would result in a decline in upper margins Old High Water Zone plant communities,
12 because none feature regular flows >45,000 cfs. The likelihood of these very high flows, which
13 would occur only under emergency dam operations, is considered very low, and would be the
14 same for all alternatives.

15 16 17 **4.6.2.2 Impacts on New High Water Zone**

18
19 Plant community types that have developed in the New High Water Zone in response to
20 Glen Canyon Dam operations include cottonwood-willow and mesquite communities, both
21 native species-dominated community types, as well as tamarisk (a nonnative species-dominated
22 community type) and arrowweed (an invasive native species-dominated community type)
23 (Ralston et al. 2014). Two native species-dominated wetland community types, marsh and shrub
24 wetland, that occur in the Fluctuation Zone are discussed in Section 4.6.2.3. Transitions between
25 plant community types, or to bare sand, are driven by specific flow events that vary among the
26 alternatives. Spring HFEs, fall HFEs, spill flows, extended low flows, extended high flows, and
27 seasons without extended high or low flows occurring during the growing or non-growing season
28 result in changes in the distribution and cover of New High Water Zone plant communities.
29 HFEs alone do not result in transitions but generally act in combination with other flow events.
30 Colorado River flows affect the composition, structure, and distribution of riparian vegetation
31 communities through the effects of drowning, scouring, sediment deposition, desiccation, and
32 maintaining alluvial groundwater levels (Sankey, Ralston et al. 2015; Ralston et al. 2014;
33 Ralston 2005, 2010, 2012; Kennedy and Ralston 2011; Kearsley et al. 2006; Porter 2002;
34 Kearsley and Ayers 1999; Stevens et al. 1995). HFEs result in sediment deposition and increased
35 water availability at higher stage elevations but little scouring, extended high flows drown and
36 scour plants and maintain ground-water levels, while extended low flows can desiccate plants,
37 especially seedlings, while providing a consistent water supply to plants at very low stage
38 elevations. Transitions and initiating flows are presented in Table G-3, in Appendix G.

39
40 Flows that result in increases or decreases in cottonwood-willow and mesquite
41 communities are given in Table 4.6-4. Alternatives with greater occurrence of transitions from
42 bare sand to native plant communities and/or maintenance of those communities (i.e., a lack of
43 transitions to bare sand) would result in greater native community cover. However, repeated
44 seasons of extended high flows, extended high flows above 50,000 cfs, or spill flows transition
45 native communities to bare sand through the processes of drowning, scouring, and burial
46 (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). All of the alternatives

1 **TABLE 4.6-4 Transitions between Riparian Community Types and the Flows That Initiate**
 2 **Transitions**

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
<i>Transitions That Increase New High Water Zone Natives</i>			
Bare sand	Cottonwood-willow	Lower separation bar	Growing season and non-growing season without extended high or low flows the same year (7 yr; slowed by non-growing-season extended high flow with growing season without extended high or low flow the same year) (Waring 1995; Ralston et al. 2008).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow next growing season (Ralston 2010).
Tamarisk	Mesquite	Upper bars/channel margin; lower channel margin	Spring HFE with growing season without extended high or low flow or extended high flow the same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
<i>Transitions That Decrease New High Water Zone Natives</i>			
Cottonwood-willow	Bare sand	Lower separation bar	Spill flow ^a ; non-growing-season extended high plus growing-season extended high same year; or growing-season extended high followed by non-growing-season extended high the next year.(Stevens and Waring 1986a)
Cottonwood-willow	Bare sand	Lower channel margin	Spill flow ^a ; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Mesquite	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow ^a or any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
<i>Transitions That Increase Wetland</i>			
Bare sand	Marsh	Lower reattachment bar	Growing season without extended high or low flow (2 yr; slowed by growing season with extended high flow) (Stevens et al. 1995; Kearsley and Ayers 1999; Ralston 2010).
Bare sand	Shrub wetland	Lower channel margin	Non-growing season without extended high or low flow plus growing season without extended high or low flow (4 yr, can be slowed by growing season with extended low flow or HFE; extended high flow starts process over) (Stevens and Waring 1986a; Porter 2002).

3

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
<i>Transitions That Decrease Wetland</i>			
Marsh, shrub wetland	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012).
Marsh, shrub wetland	Bare sand	Lower reattachment bar	Spill flow ^a ; any season with extended high flow followed by an extended high flow next growing season; growing season with extended high flow followed by a non-growing season with extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Shrub wetland	Bare sand	Lower channel margin	Any season with extended high flow over 25,000 cfs (Stevens and Waring 1986a).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow the next growing season (Ralston 2010).
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
<i>Transitions That Increase Tamarisk</i>			
Marsh, shrub wetland, arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002).
Bare sand	Tamarisk	Lower separation bar; lower channel margin	Non-growing season with extended high flow, or spring HFE plus growing season with extended low flow the same year (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012; Sher et al. 2000).
Bare sand	Tamarisk	Lower reattachment bar	Growing season with extended low flow (Stevens and Waring 1986a; Porter 2002; Sher et al. 2000).
Bare sand	Tamarisk	Upper bar/channel margin	Spring HFE plus growing season with extended high flow the same year (Sher et al. 2000; Mortenson et al. 2012).
<i>Transitions That Decrease Tamarisk</i>			
Tamarisk	Bare sand	Lower separation bar	Spill flow ^a ; non-growing-season extended high flow plus growing-season extended high flow same year; or growing-season extended high flow followed by non-growing-season extended high flow the next year (Stevens and Waring 1986a).

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Decrease Tamarisk (Cont.)			
Tamarisk	Bare sand	Lower reattachment bar	Spill flow ^a ; 4 consecutive seasons of non-growing-season extended high flow plus growing-season extended high flow; growing-season extended high flow (4 consecutive years) (Stevens and Waring 1986a; Kearsley and Ayers 1999).
Tamarisk	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow ^a ; any season extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Tamarisk	Mesquite	Lower channel margin; upper bar/channel margin	Spring HFE with growing season without extended high or low flow or extended high same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
Transitions That Increase Arrowweed			
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
Bare sand	Arrowweed	Upper bar/channel margin	Non-growing season with extended low flow, or seasons without extended high or low flow, or non-growing season with extended high flow, plus growing season with extended low flow, or seasons without extended high or low flow, or growing season with extended high flow; same year (3–6 yr, extended high flows increase the rate, slowed by fall HFE) (Waring 1995).
Transitions That Decrease Arrowweed			
Arrowweed	Bare sand	Lower reattachment bar	Spill flow ^a ; any season with extended high flow followed by an extended high flow the next growing season; growing season with extended high flow followed by a non-growing season extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Arrowweed	Bare sand	Upper bar/channel margin	Spill flow ^a ; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002).

^a Spill flows are releases through the spillway and are non-discretionary emergency actions that do not vary among alternatives.

Source: Ralston et al. (2014).

1 would result in a decrease in native plant community cover (see discussions below under
2 individual alternatives). However, annual hydrology has a greater effect on the change in native
3 community types than the operational characteristics of the alternatives.
4

5 Flows that result in increases or decreases in tamarisk are given in Table 4.6-4. The
6 overall cover of tamarisk-dominated communities would be expected to increase under
7 Alternatives C, F, and G, each of which are expected to produce frequent transitions to tamarisk
8 communities, in large part because they frequently have extended high flows, extended low
9 flows, and spring HFEs. This combination of flows encourages transitions to tamarisk because
10 tamarisk increases when high flows coincide with seed release during spring and early summer,
11 followed by lower flows, all of which results in establishment of seedlings above the elevation of
12 subsequent floods (Mortenson et al. 2012; Stevens and Siemion 2012). Also, under these
13 alternatives, various community types frequently shift to bare sand, which then shifts to tamarisk.
14 Each of these alternatives has more extended low flows and more spring HFEs than the other
15 alternatives. The overall cover of the tamarisk is expected to decrease under Alternatives A, B,
16 D, and E. Each of these alternatives has frequent extended high flows, which result in
17 consecutive seasons and consecutive years of extended high flows. Two or more years of
18 extended high flows are required for tamarisk to be removed by drowning, leaving a bare sand
19 lower reattachment bar, or two consecutive seasons (growing and non-growing) on a lower
20 separation bar (Kearsley and Ayers 1999; Stevens and Waring 1986a).
21

22 The presence of the tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil
23 (*Coniatus* spp.) along much of the Colorado River below Glen Canyon Dam has resulted in
24 defoliation of tamarisk in many areas, with an estimated 70% defoliation at some sites
25 (Johnson et al. 2012). Considerable uncertainty still exists regarding the long-term effects of the
26 beetle and weevil on the tamarisk population below the dam and subsequent effects on
27 ecosystem dynamics within the New High Water Zone. The replacement of tamarisk by other
28 species and the timing of replacement would be affected by flow characteristics. Tamarisk may
29 not establish as readily on bare sand substrates, or transition from other community types, as in
30 the past (and described above) if seed sources are reduced. Additionally, tamarisk communities
31 may become less stable and more easily removed by high flows than in the past. Therefore,
32 increases in tamarisk that would be expected to result under Alternatives C, F, and G, may be
33 less than expected, and decreases of tamarisk under Alternatives A, B, D, and E may be greater
34 than expected.
35

36 Flows that would result in increases or decreases in arrowweed are given in Table 4.6-4.
37 The overall cover of the arrowweed community type would be expected to increase under
38 Alternatives A, B, and E; under these alternatives, bare sand would transition to arrowweed
39 rather than tamarisk because there are few spring HFEs and/or few growing-season extended
40 high flows, both of which promote the establishment of tamarisk on bare sand, and, except in
41 Alternative B, arrowweed would transition from marsh because of growing-season extended low
42 flows (Porter 2002). Once established, arrowweed would tend to remain for many years under
43 these alternatives. HFEs alone are not effective at reducing arrowweed as burial typically results
44 in resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth occurs
45 (Ralston 2012). Arrowweed would decrease under Alternatives C, D, F, and G, usually by
46 transitioning to bare sand with repeated extended high flows (Ralston 2010; Stevens and

1 Waring 1986a), but often by transitioning to tamarisk. The hydrology of the river (e.g., wet years
2 vs. dry years), however, has a greater effect on the change in arrowweed than the characteristics
3 of the alternatives. Drier years tend to have fewer extended high flows resulting in more
4 arrowweed due to fewer transitions to bare sand or tamarisk.

5
6 Given that under all alternatives vegetation condition degrades to some degree,
7 experimental riparian vegetation restoration activities are planned under all alternatives except
8 for Alternative A. These activities are expected to modify the cover and distribution of plant
9 communities along the Colorado River and improve the vegetation conditions. These restoration
10 activities include removal of nonnative plants and prevention of new introductions, native plant
11 restoration, clearing of undesirable plants from campsites, and removal of vegetation that blocks
12 wind transport of sediment. Plantings of native species, such as Goodding's willow and
13 cottonwood, would be conducted to increase and maintain populations of these species.
14 Restoration of native species would include the collection of propagules (seeds, cuttings, poles,
15 or whole plants) from riparian areas in both the river corridor and side canyons. Removal of
16 nonnative plants would include mechanical means (e.g., cutting), smothering, spot burning, or
17 use of herbicides. Monitoring of riparian areas subsequent to the implementation of any
18 alternative would direct the specific locations and degree of implementation of non-flow actions.
19 Nonnative species targeted for removal would be those considered the greatest threat to park
20 resources and having a high potential for successful control (Table 4.6-5). Control and removal
21 of the native arrowweed would be conducted where this species is encroaching on campsites.
22 Full-scale restoration at selected sites or sub-reaches would include removal of tamarisk and
23 replanting and seeding of natives. The acreage that would be targeted for priority treatment
24 would vary by alternative, depending on expected changes in riparian community types. An
25 estimate of the change in acreage of tamarisk or arrowweed under each of the alternatives is
26 given in Section 4.6.3. Alternatives that result in greater increases in these species would be
27 expected to also result in a greater extent of targeted restoration. Therefore, differences among
28 alternatives in changes of tamarisk or arrowweed may be somewhat less than indicated by flow
29 effects alone. Restoration actions would be expected to occur at limited locations, and these areas
30 would likely only comprise a small proportion of the riparian area below Glen Canyon Dam.

31 32 33 **4.6.2.3 Wetlands**

34
35 Wet marsh communities of flood-tolerant herbaceous species that occur on low elevation
36 areas of reattachment bars within the Fluctuation Zone (i.e., the range of normal operational
37 fluctuations between the elevations of 5,000 and 25,000 cfs flows) have developed in response to
38 frequent inundation (daily for at least part of the year) (Stevens et al. 1995; Ralston 2005, 2010).
39 These marsh communities (with common reed and cattail the dominant species) occur on fine-
40 grained silty loam soils in low-velocity environments on lower areas of eddy complex sandbars,
41 which, although easily scoured by high flows, can redevelop quickly. Clonal wetland species
42 such as cattail, common reed, and willow are adapted to burial and regrowth and recover
43 following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Native flood-adapted
44 species increase in low-elevation areas following growing-season steady high flows, potentially
45 by vegetative reproduction (Porter 2002; Ralston 2011). Shrub wetland communities (with
46 coyote willow, seep willow, and horsetail the dominant species) occur on sandy soils of

1
2

**TABLE 4.6-5 Priority Nonnative Species Identified
 for Control within the Colorado River Corridor**

Scientific Name	Common Name
<i>Rhaponticum repens</i>	Russian knapweed
<i>Alhagi maurorum</i>	camelthorn
<i>Brassica tournefortii</i>	Sahara mustard
<i>Convolvulus arvensis</i>	black bindweed
<i>Cortaderia selloana</i>	Pampas grass
<i>Echinochloa crus-galli</i>	barnyardgrass
<i>Eragrostis curvula</i>	weeping love grass
<i>Elaeagnus angustifolia</i>	Russian olive
<i>Lepidium latifolium</i>	perennial pepperweed
<i>Malcolmia africana</i>	African mustard
<i>Phoenix dactylifera</i>	date palm
<i>Saccharum ravennae</i>	Ravenna grass
<i>Salsola tragus</i>	Russian thistle
<i>Schedonorus arundinaceus</i>	tall fescue
<i>Sisymbrium altissimum</i>	tumble mustard
<i>Sisymbrium irio</i>	London rocket
<i>Solanum elaeagnifolium</i>	silverleaf nightshade
<i>Sonchus asper</i>	spiny sowthistle
<i>Sonchus oleraceus</i>	common sowthistle
<i>Tamarix aphylla</i>	athel
<i>Tamarix</i> spp.	salt cedar
<i>Tribulus terrestris</i>	puncture vine
<i>Ulmus pumila</i>	Siberian elm

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reattachment bars and channel margins, below the 25,000 cfs stage, that are less frequently inundated. Mortality of horsetail occurs at higher elevations above the water table during growing-season low steady flows (Porter 2002). Large daily fluctuations increase the area of saturated soil, and thus the sandbar area available for wetland species establishment (Stevens et al. 1995; Carothers and Aitchison 1976; Kearsley et al. 2006). The reduction of daily fluctuations may increase the establishment of wet marsh species at lower elevations and promote the transition of higher elevation marshes to woody phreatophyte species such as tamarisk or arrowweed (Stevens et al. 1995). Periodic flooding and drying tends to increase diversity and productivity in wetland communities (Reclamation 2011b; Stevens et al. 1995). Although low-elevation plants in marshes in Marble Canyon and Grand Canyon, such as cattail, common reed, and willow, may become buried with coarse sediment, recovery generally occurs within 6–8 months (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Low steady flows can cause some wetland patches to dry out, resulting in considerable mortality (Porter 2002). Sustained high releases reduce wetland vegetation cover to less than 20% on lower reattachment bars, allowing tamarisk to occupy open space, if sustained low releases occur in the next growing season (Ralston et al. 2014; Sher et al. 2000). Extended high flows typically scour herbaceous vegetation; however, most woody plants often remain (Ralston et al. 2014). Thus, extended high flows followed by extended low flows in the following growing season result in a transition from

1 shrub wetland to a cottonwood-willow community on channel margins because of an increase in
2 overstory cover and a decrease in herbaceous understory plants (Ralston 2010).

3
4 Flows that result in increases or decreases in marsh or shrub wetland communities are
5 given in Table 4.6-4. A transition from marsh to shrub wetland occurs on lower reattachment
6 bars with 4 years of consecutive seasons of low fluctuating flows or non-growing-season
7 sustained low flows (Ralston et al. 2014; Stevens et al. 1995). A fall or spring HFE delays the
8 transition for 1 year; however, an extended high flow before the transition removes the
9 established plants (Ralston et al. 2014).

10
11 Wetland communities generally transition only from bare sand or other wetlands
12 (Ralston et al. 2014; Stevens et al 1995); they can transition back to bare sand or to arrowweed,
13 tamarisk, or cottonwood-willow communities (Mortenson et al 2012; Ralston 2010; Porter 2002;
14 Sher et al. 2000; Kearsley and Ayers 1999; Stevens and Waring 1986a). A greater occurrence of
15 transitions from bare sand to wetlands and/or maintenance of wetlands (lack of transitions to
16 other community types) would result in greater wetland cover. Alternatives that include frequent
17 extended low flows, such as annually for Alternative F, or extended high flows followed by
18 extended low flows tend to result in transitions of wetlands to other plant community types. All
19 of the alternatives are expected to result in a decrease in wetland cover, with particularly large
20 decreases for Alternative F. The relative change in cover (final based on model results/initial) of
21 wetland community types is presented in Figure 4.6-4.

22 23 24 **4.6.2.4 Special Status Plant Species**

25
26 Impacts on special status plant species that are known to occur along the Colorado River
27 from Glen Canyon Dam to Lake Mead are summarized in Table 4.6-6. Scientific names, listing
28 status, and habitat are presented in Section 3.6, Table 3.6-2. The analyses of impacts for special
29 status plant species is similar to the analysis for other vegetation and relies on an evaluation of
30 impacts on the habitat associated with each species.

31
32 Species of active floodplains occur above the elevation of daily releases (25,000 cfs) but
33 within the stage elevation of HFEs (45,000 cfs). These include Grand Canyon evening primrose
34 (*Camissonia specuicola* ssp. *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var.
35 *mohavensis*), lobed daisy (*Erigeron lobatus*), and may include giant helleborine (*Epipactis*
36 *gigantea*). These species are generally not affected by HFEs because of their short duration,
37 however, Alternatives C, D, and G include extended duration HFEs (up to 250 hr under
38 Alternative D and 336 hr under Alternative G), while Alternative F has annual spring HFEs. A
39 slightly increased potential for burial from these HFEs could result in an increased potential for
40 impacts on special status species because of their small populations.

41
42 Species of the Lake Mead shoreline include sticky buckwheat (*Eriogonum viscidulum*),
43 Geyer's milkvetch (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*).
44 These species are generally not affected by fluctuations in the Lake Mead surface elevation, as
45 under current operations. However, alternatives that raise the reservoir surface elevation, such as
46

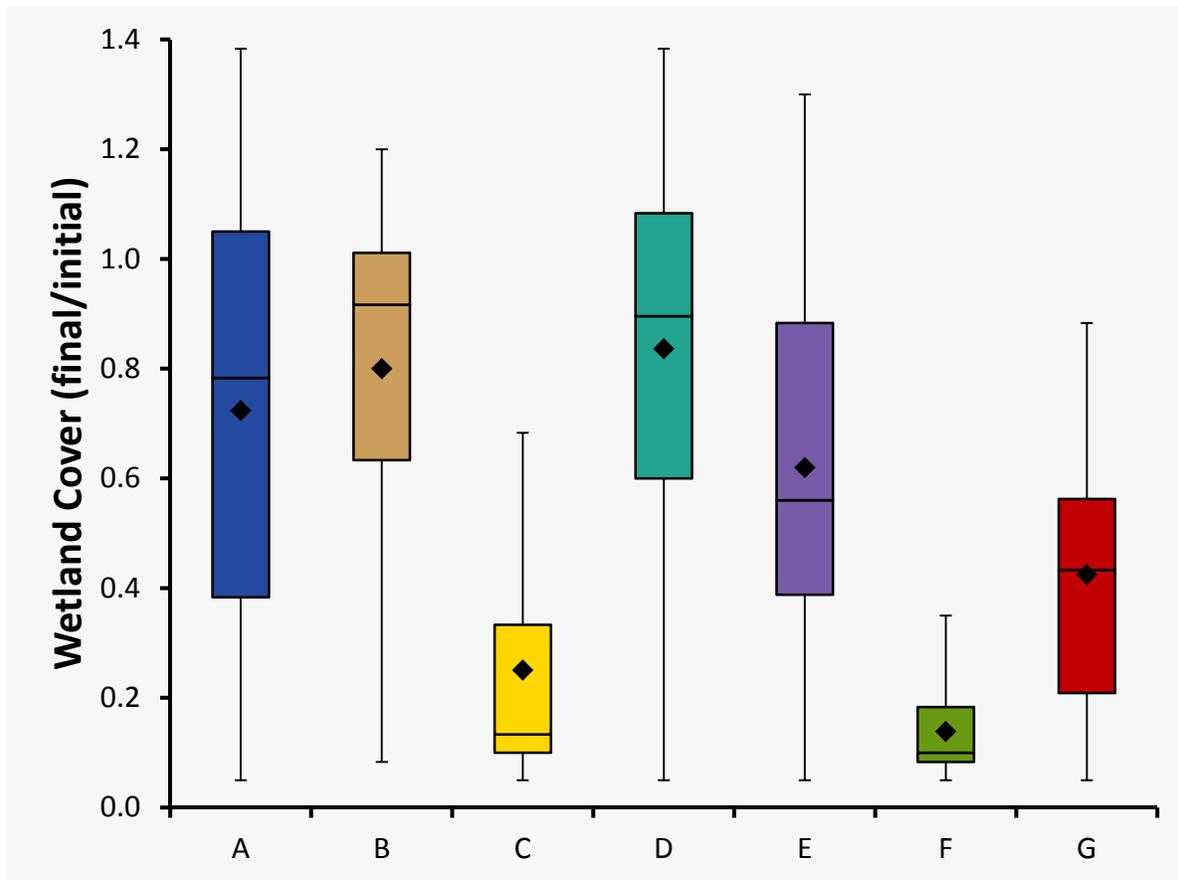


FIGURE 4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a Vegetation Model (Metric represents the proportion of the estimated amount of wetland vegetation types at the end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change over the LTEMP period; values >1 indicate an increase; values <1 indicate a decrease. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

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the minor elevation increase in April-June under Alternative F (see Figure 4.2-4), inundate the shoreline habitat for these species, potentially resulting in drowning of individuals.

Species of inactive floodplains, Marble Canyon spurge (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*), occur above the stage elevation of HFEs (45,000 cfs) but below the elevation of the desert scrub community. These species are not directly affected by dam operations. However, the annual spring HFEs that occur under Alternative F potentially provide a slight benefit to these species through frequent increases in soil moisture.

Species of the fluctuation zone are inundated by daily operations and are typically associated with wetland communities. These include satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*). The loss of wetland community cover under all alternatives would result in a loss of habitat for these species.

1 **TABLE 4.6-6 Summary of Impacts on Special Status Plant Species under LTEMP Alternatives**

Species	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Species of active floodplains (25,000–45,000 cfs)</i> Grand Canyon evening primrose (<i>Camissonia specuicola</i> ssp. <i>Hesperia</i>), Mohave prickly pear (<i>Opuntia phaeacantha</i> var. <i>mohavensis</i>), lobed daisy (<i>Erigeron lobatus</i>), giant helleborine (<i>Epipactis gigantea</i>)	No impact from current operations; located above the level of daily operations.	Same as Alternative A.	Small potential for impacts from extended duration HFEs.	Small potential for impacts from extended duration HFEs.	Same as Alternative A.	Small potential for impacts from high frequency of HFEs.	Small potential for impacts from extended duration HFEs.
<i>Species of the Lake Mead shoreline</i> sticky buckwheat (<i>Eriogonum viscidulum</i>), Geyer’s milkvetch (<i>Astragalus geyeri</i>), Las Vegas bear poppy (<i>Arctomecon californica</i>)	No impact on species from current operations.					Minor increase in April–June in Lake Mead shoreline elevation inundating habitat; adverse impact.	Similar to Alternative A.
<i>Species of inactive floodplains (>45,000 cfs)</i> Marble Canyon spurge (<i>Euphorbia aaron-rossii</i>), hop-tree (<i>Ptelea trifoliata</i>)	No impact from current operations; located above dam operational effects.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Small potential for benefit from high frequency of spring HFEs.	Same as Alternative A.
<i>Species of fluctuation zones and wetlands</i> satintail (<i>Imperata brevifolia</i>), rice cutgrass (<i>Leersia oryzoides</i>), American bugleweed (<i>Lycopus americanus</i>)	Adverse impact; wetland habitat decreases.						

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1 **4.6.3 Alternative-Specific Impacts**
2

3 The resources addressed in this section include the riparian plant communities of the New
4 High Water Zone and the Fluctuation Zone. The mechanisms underlying New High Water Zone
5 vegetation changes associated with hydrologic events, and the associated research supporting
6 those mechanisms, are described in Section 4.6.2. Details of the model and calculation of the
7 performance metrics can be found in Appendix G. Although the model is not spatially explicit
8 and, therefore, cannot predict changes to plant communities on individual sandbars and channel
9 margin depositional features, acreage changes that are calculated from the currently mapped
10 extent of each of the modeled community types are presented in this section, based on the
11 modeled increase or decrease in each type.
12

13 As noted in Section 4.6.2.2, experimental vegetation restoration actions would also be
14 implemented that would result in modifications to the riparian vegetation communities in the
15 New High Water Zone. Although these areas may be a relatively small proportion of the riparian
16 area below Glen Canyon Dam, implementation of non-flow actions would result in the reduction
17 of nonnative species populations, including tamarisk, and increases in native species populations
18 on sandbars and channel margin areas. Consequently, the native/nonnative ratios (as well as
19 changes in tamarisk) identified for each alternative in this section would likely be higher with the
20 implementation of non-flow actions under those alternatives. Similarly, the arrowweed metric
21 presented for each alternative would likely be higher with the implementation of non-flow
22 actions under those alternatives.
23
24

25 **4.6.3.1 Alternative A (No Action Alternative)**
26

27 Under Alternative A (the No Action Alternative), base operations (i.e., the intervening
28 flows that occur between HFEs or other experimental flow manipulations) are MLFF, the flow
29 regime that was put in place by the 1996 ROD (Reclamation 1996) for the 1995 Glen Canyon
30 EIS (Reclamation 1995). This alternative includes sediment-triggered spring and fall HFEs
31 through 2020 (no spring HFEs until 2016) that would be implemented according to the HFE
32 protocol developed and evaluated in the HFE EA (Reclamation 2011b). Alternative A has higher
33 monthly volumes in the high electricity demand months of December, January, July, and August
34 than in other months. This alternative has fewer spring and fall HFEs than other alternatives,
35 occasional extended low flows, and more frequent extended high flows than most other
36 alternatives, the latter being particularly frequent in the growing season.
37

38 Frequent extended high flows would result in a decrease in the native community types
39 including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and
40 Waring 1986a). Repeated seasons of extended high flows have been observed to cause the
41 transition of native communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens
42 and Waring 1986a). This is supported by modeling results which indicate a 17% (55.2 ac) overall
43 decrease in native plant community cover and 28% (1.3 ac) decrease in wetland community
44 cover.
45

1 The frequent extended high flows and few extended low flows (along with few spring
2 HFEs) would tend to remove tamarisk and would be accompanied by a reduced level of
3 establishment of tamarisk (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000;
4 Kearsley and Ayers 1999; Stevens and Waring 1986a), resulting in an overall decrease in
5 tamarisk-dominated communities. Because the decrease in tamarisk modeled (58.4 ac) exceeds
6 the decrease in native community types (55.2 ac), the ratio of native to nonnative community
7 types would be expected to increase by about 5% under Alternative A.

8
9 Frequent extended high flows, few spring HFEs, and occasional fall HFEs would also
10 promote the establishment of arrowweed on upper elevation areas (Waring 1995). Based on
11 results of modeling, Alternative A is expected to result in a 25% (44.5 ac) increase in the
12 arrowweed community type.

13
14 The model results for each of the metrics are presented in Table 4.6-3 and shown in
15 Figures 4.6-2 and 4.6-3.

16
17 In summary, Alternative A would result in beneficial changes associated with an increase
18 in the ratio of native to nonnative community types as a result of a decrease in tamarisk cover
19 (5% increase in ratio, 58.4 ac decrease in tamarisk). These benefits could be greater than
20 anticipated depending on the effects of the tamarisk leaf beetle in the area and the non-flow
21 vegetation restoration experiment. However, Alternative A is also expected to result in adverse
22 effects associated with a decrease in native cover (17% overall decrease in native plant
23 community cover; 28% decrease in wetland community cover) and native diversity (2% decrease
24 in native diversity over the LTEMP period due to decrease in wetland communities), and an
25 increase in arrowweed cover (25% increase in cover). Several special status species could be
26 impacted as a result of the decrease in wetland community cover. The Old High Water Zone
27 would continue narrowing. Although the non-flow vegetation restoration experiment may
28 decrease these adverse effects to some extent, it is expected that Alternative A would result in a
29 movement away from the riparian vegetation resource goal over the LTEMP period. The
30 tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

31 32 33 **4.6.3.2 Alternative B**

34
35 Alternative B includes spring and fall HFEs (the number of HFEs not to exceed one
36 every other year), with few spring HFEs, similar to Alternative A, but slightly more fall HFEs
37 compared to Alternative A. TMFs are also included in this alternative. This alternative has the
38 same monthly pattern in release volume as the Alternative A; however, due to the large daily
39 fluctuations, Alternative B has no extended low flows and has frequent extended high flows, at a
40 slightly greater frequency compared to Alternative A.

41
42 Frequent extended high flows would result in a decrease in native community types
43 including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and
44 Waring 1986a); however, the decrease, including wetland decrease, is less (statistically
45 significant) than under Alternative A. Repeated seasons of extended high flows transition native
46 communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a).

1 This is supported by modeling results which indicate a 15% (48.3 ac) overall decrease in native
2 plant community cover and 20% (0.9 ac) decrease in wetland community cover. Although the
3 amount of native cover would be expected to decrease under this alternative, the diversity of
4 native community types is expected to increase 3%. This alternative would result in a greater
5 area of wet marsh than Alternative A primarily because of a lack of extended low flows that
6 would contribute to a loss of marsh (Sher et al. 2000; Porter 2002).
7

8 The frequent extended high flows would result in a tendency to remove tamarisk through
9 repeated effects (consecutive seasons or years) of drowning, limited growth, and depleted energy
10 reserves (Kearsley and Ayers 1999; Stevens and Waring 1986a), and a lack of extended low
11 flows (along with few spring HFEs) would result in a reduced level of tamarisk seedling
12 establishment (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000), resulting in
13 an overall decrease in tamarisk-dominated communities, with there being more of a decrease
14 than under Alternative A. Because of the large decrease in tamarisk-dominated communities
15 modeled (71.4 ac) and smaller decrease in native cover (48.3 ac), the ratio of native to nonnative
16 community types under this alternative would increase 15% and is significantly higher
17 (statistically significant) than that for Alternative A.
18

19 Frequent extended high flows, few spring HFEs, and more fall HFEs would also promote
20 the establishment of arrowweed on upper elevation areas (Waring 1995). Based on results of
21 modeling, Alternative B is expected to result in a 19% increase (33.3 ac) in arrowweed, although
22 at a level less than under Alternative A (however, the difference is not statistically significant).
23

24 The model results for each of the metrics are presented in Table 4.6-3 and shown in
25 Figures 4.6-2 and 4.6-3. One experimental element, hydropower improvement flows, results in a
26 considerable increase in the frequency of extended high flows, resulting in a greater decrease in
27 native community types (150.1 ac) and tamarisk (107.0 ac) and a slightly greater increase in
28 arrowweed (41.9 ac) (although not a statistically significant difference).
29

30 In summary, Alternative B would result in beneficial changes associated with an increase
31 in native diversity (3% increase over the LTEMP period, a higher diversity than Alternative A),
32 and an increase in the ratio of native to nonnative community types as a result of a decrease in
33 tamarisk cover (a 15% increase in ratio, a higher ratio than under Alternative A; 71.4 ac decrease
34 in tamarisk, a greater decrease than under Alternative A). These benefits could be greater than
35 anticipated depending on the effects of the tamarisk leaf beetle in the area and the non-flow
36 vegetation restoration experiment. However, Alternative B is also expected to result in adverse
37 effects associated with a decrease in native cover (15% overall decrease in native plant
38 community cover, 20% decrease in wetland community cover; both less of a decrease than under
39 Alternative A) and an increase in arrowweed cover (19% increase in cover, less than under
40 Alternative A). Several special status species could be impacted as a result of the decrease in
41 wetland community cover. The Old High Water Zone would continue narrowing. Although the
42 non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it
43 is expected that Alternative B would result in a movement away from the riparian vegetation
44 resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater
45 decrease in tamarisk. Alternative B would result in higher fluctuation flows, although flows prior
46 to the 1996 ROD (Reclamation 1996) had a much greater daily range than Alternative B

1 (28,500–30,500 cfs; Reclamation 1995). The shift from those flows to MLFF resulted in a
2 general reduction of marsh habitat and an increase in tamarisk and arrowweed, particularly in the
3 upper elevations of the former Fluctuation Zone (Ralston 2005). An increase in fluctuations
4 would not necessarily reverse those trends but would be expected to result in greater marsh area
5 (Stevens et al. 1995) and potentially less tamarisk and arrowweed than under MLFF of
6 Alternative A. These increases would not be realized under experimental hydropower
7 improvement flows.
8
9

10 **4.6.3.3 Alternative C**

11
12 Alternative C includes spring and fall HFEs that could be triggered by Paria River
13 sediment inputs in all years during the LTEMP period and proactive spring HFEs (24 hr,
14 45,000 cfs HFE) that would be tested in April, May, or June in high-volume years. Lower
15 fluctuation levels conserve more sediment, and therefore result in more triggered HFEs. As a
16 result, this alternative has a far greater frequency of fall and spring HFEs compared to
17 Alternatives A and B (see Section 4.2). TMFs are also included in this alternative. Alternative C
18 has highest monthly release volumes in December, January, and July, and lower volumes from
19 August through November; volumes in February through June would be proportional to power
20 contract delivery rates. This alternative has a higher frequency of extended low flows compared
21 to Alternative A and far fewer growing or non-growing seasons without extended high or low
22 flows. Although Alternative C generally has fewer growing-season extended high flows than
23 Alternative A, it has a slightly greater frequency of non-growing-season extended high flows.
24

25 Repeated high flows have been observed to shift vegetation communities to bare sand
26 (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). A greater frequency of
27 HFEs, very few seasons without extended high or low flows, and far more extended low flows
28 would result in a lack of establishment of native community types; consequently, native
29 community types including wetlands decrease under this alternative (Ralston et al. 2008;
30 Waring 1995; Anderson and Ruffner 1987), with the decrease being greater (statistically
31 significant) than that under Alternative A. This alternative has the greatest decrease in native
32 cover of all the alternatives and the second greatest decrease in wetlands (only Alternative F is
33 greater). Extended low flows during the growing season contribute to the shifting of wetland
34 communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002),
35 and the establishment of shrub wetland communities on bare sand can be slowed by growing-
36 season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This is supported
37 by modeling results which indicate a 37% (117.7 ac) overall decrease in native plant community
38 cover and 75% (3.4 ac) decrease in wetland community cover. The diversity of native
39 community types decreases 8% under this alternative is lower than that under Alternative A,
40 primarily due to the large decreases in the wetland community types.
41

42 Growing-season extended low flows can contribute to the shifting of wetland and
43 arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and
44 Waring 1986a; Porter 2002) and promote tamarisk establishment on bare sand (Stevens and
45 Waring 1986a; Sher et al. 2000; Porter 2002). Spring HFEs can also contribute to tamarisk
46 establishment on bare sand (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012;

1 Sher et al. 2000). Consequently, tamarisk-dominated communities would be expected to increase
2 considerably under Alternative C (104.0 ac, only Alternative F has a greater increase). Because
3 of the large decrease in native community types (117.7 ac), the ratio of native to nonnative
4 community types under this alternative decreases 54% and is significantly lower (statistically
5 significant) than under Alternative A, and is the largest difference between the two alternatives.
6

7 Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999;
8 Ralston 2010), while extended low flows contribute to tamarisk replacing arrowweed
9 (Sher et al. 2000; Stevens and Waring 1986a; Porter 2002). Arrowweed would therefore decrease
10 14 % (25.1 ac) based on results of modeling, under this alternative, a statistically significant
11 difference from the increase under Alternative A. Note that this reduction is considered a benefit
12 because of the invasive nature of this species and associated impacts on meeting sediment
13 resource objectives and recreation goals for camping.
14

15 The model results for each of the metrics are presented in Table 4.6-3 and shown in
16 Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows and
17 TMFs, which have little effect on the results, and proactive spring HFES, which result in twice
18 the tamarisk increase (more bare sand becoming tamarisk rather than arrowweed) and a decrease
19 in arrowweed.
20

21 In summary, Alternative C would result in a beneficial change associated with a decrease
22 in arrowweed cover (14% decrease in cover, less cover than the increase under Alternative A).
23 This benefit could be greater than anticipated depending on the effects of the non-flow
24 vegetation restoration experiment. However, Alternative C is also expected to result in adverse
25 effects associated with a decrease in native cover (37% overall decrease in native plant
26 community cover, 75% decrease in wetland community cover; both greater decreases than under
27 Alternative A), decrease in native diversity (8% decrease, lower diversity than under
28 Alternative A), and decrease in the ratio of native to nonnative community types (54% decrease
29 in ratio, a lower ratio than under Alternative A; 104 ac increase in tamarisk, greater tamarisk
30 cover than under Alternative A). Several special status species could be impacted as a result of
31 the decrease in wetland community cover. There is a small potential for impacts on active
32 floodplain special status species. The Old High Water Zone would continue narrowing, although
33 more spring HFES than Alternative A could potentially result in higher survival rates of plants at
34 lower elevations of the zone. Although the non-flow vegetation restoration experiment may
35 decrease these adverse effects to some extent, it is expected that Alternative C would result in a
36 movement away from the riparian vegetation resource goal over the LTEMP period. The
37 tamarisk leaf beetle may contribute to reducing the increase in tamarisk.
38
39

40 **4.6.3.4 Alternative D (Preferred Alternative)**

41

42 This alternative includes a variety of HFE types throughout the LTEMP period including:
43 sediment-triggered spring (March–April) and fall (October–November) HFES; proactive spring
44 HFES (24 hr, 45,000 cfs) would be tested (April, May, or June) in high-volume years; no spring
45 HFES in the first two years; and extended-duration fall HFES (up to 250 hr duration, up to
46 45,000 cfs), up to four in 20-year period. More even monthly volumes conserve more sediment

1 and therefore result in more triggered HFEs. As a result, Alternative D has a considerably greater
2 frequency of fall and spring HFEs compared to Alternatives A and B (Section 4.2). TMFs are
3 also included in this alternative. This alternative has very few growing-season extended low
4 flows, as well as slightly fewer non-growing-season extended low or high flows, due to the
5 monthly pattern of flows as well as the amount of daily fluctuations. Alternative D has frequent
6 growing-season extended high flows but fewer than under Alternative A. Seasons without
7 extended low or high flows are frequent, especially non-growing seasons.

8
9 Frequent extended high flows would result in a decrease in native community types,
10 including wetlands, although less (statistically significant) of a decrease than under
11 Alternative A. Growing-season extended high flows can contribute to the loss of New High
12 Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and
13 Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. A greater
14 frequency of HFEs would tend to slow establishment of shrub wetland on bare sand; extended
15 high flows prevent establishment of this community type (Stevens and Waring 1986a;
16 Porter 2002) and establishment of wet marsh (Stevens et al. 1995; Kearsley and Ayers 1999;
17 Ralston 2010). However, few extended low flows during the growing season would limit the
18 occurrence of wetland communities shifting to tamarisk or arrowweed (Sher et al. 2000;
19 Mortenson et al. 2012; Porter 2002). This is supported by modeling results, which indicate a 12%
20 (39.5 ac) overall decrease in native plant community cover and 16% (0.8 ac) decrease in wetland
21 community cover. The diversity of native community types, a 2% increase, is significantly
22 greater (statistically significant) under this alternative than under Alternative A because of a
23 greater degree of evenness in native community types, as this alternative would result in a greater
24 area of wet marsh than under Alternative A, which has more frequent extended high flows.

25
26 Repeated extended high flows, as occur under this alternative, can remove tamarisk
27 (Stevens and Waring 1986a; Kearsley and Ayers 1999), resulting in a decrease in tamarisk-
28 dominated communities, although less of a decrease than under Alternative A. The low number
29 of growing-season extended low flows would limit tamarisk establishment (Sher et al. 2000;
30 Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). However, spring HFEs and
31 growing-season extended high flows can promote the establishment of tamarisk (Sher et al.
32 2000; Mortenson et al. 2012). Because the decrease in native community types is greater than the
33 decrease in tamarisk (22.4 ac) based on results of modeling, the ratio of native to nonnative
34 community types under this alternative decreases and is lower than under Alternative A
35 (the difference is statistically significant).

36
37 Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999;
38 Ralston 2010). The establishment of arrowweed on upper elevation areas is slowed by fall HFEs
39 (Waring 1995). In addition, the low number of extended low flows during the growing season
40 would limit the occurrence of wetland communities shifting to arrowweed (Porter 2002). Based
41 on results of modeling arrowweed would therefore decrease 10% (17.1 ac) under this alternative,
42 a statistically significant difference from the increase under Alternative A. Note that this
43 reduction is considered a benefit because of the invasive nature of this species and associated
44 impacts on meeting sediment resource objectives and recreation goals for camping.

1 The model results for each of the metrics are presented in Table 4.6-3 and shown in
2 Figures 4.6-2, 4.6-3, and 4.6-8. Experimental elements of this alternative include low summer
3 flows, TMFs, and low flows for benthic invertebrate production. Low summer flows result in a
4 greater reduction in native community types and an increase in arrowweed due to more growing-
5 season extended low flows. TMFs would result in a greater reduction in native cover and less of
6 an increase in arrowweed due to a loss of marsh to arrowweed from occasional extended low
7 flows. Benthic invertebrate production flows do not result in any statistically significant
8 differences in performance metrics.

9
10 In summary, Alternative D would result in a beneficial change associated with an
11 increase in native diversity (2% increase, greater diversity than under Alternative A) and
12 decrease in arrowweed cover (10% decrease, lower cover than under Alternative A). These
13 benefits could be greater than anticipated depending on the effects of the non-flow vegetation
14 restoration experiment. However, Alternative D is also expected to result in adverse effects
15 associated with a decrease in native cover (12% overall decrease in native plant community
16 cover, 16% decrease in wetland community cover; both decreases less than under Alternative A)
17 and a decrease in the ratio of native to nonnative community types (5% decrease in ratio, a lower
18 ratio than under Alternative A; 22.4 ac decrease in tamarisk, less of a decrease than under
19 Alternative A). Several special status species could be impacted as a result of the decrease in
20 wetland community cover. There is a small potential for impacts on active floodplain special
21 status species. The Old High Water Zone would continue narrowing, although more spring HFEs
22 than Alternative A could potentially result in higher survival rates of plants at lower elevations of
23 the zone. Although the non-flow vegetation restoration experiment may decrease these adverse
24 effects to some extent, it is expected that Alternative D would result in a movement away from
25 the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may
26 contribute to a greater decrease in tamarisk.

27 28 29 **4.6.3.5 Alternative E**

30
31 This alternative includes sediment-triggered spring and fall HFEs implemented according
32 to the HFE protocol (Reclamation 1995) with the exception that no spring HFEs would be
33 implemented in first the 10 years. As a result, Alternative E has a greater frequency of HFEs,
34 particularly fall HFEs, than Alternative A (Section 4.2). TMFs are also included in this
35 alternative. Lower monthly water volumes would occur in August, September, and October. This
36 alternative has frequent growing-season extended high flows but fewer than under Alternative A,
37 and slightly more growing-season extended low flows. The non-growing season frequently has
38 no extended high or low flows.

39
40 Frequent extended high flows would result in a decrease in the native community types
41 including wetlands, with there being more (statistically significant) of a decrease than
42 Alternative A. Growing-season extended high flows can contribute to the loss of New High
43 Water Zone native communities (Stevens and Waring 1986a) including wetlands (Stevens and
44 Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. These flows, in
45 combination with extended low flows, can result in wetlands transitioning to tamarisk
46 (Sher et al. 2000; Mortenson et al. 2012). The establishment of shrub wetland communities on

1 bare sand can be slowed by growing-season extended low or high flows or HFEs (Stevens and
2 Waring 1986a,b; Porter 2002). Extended low flows contribute to wetlands becoming replaced by
3 arrowweed (Porter 2002). This is supported by modeling results which indicate a 20% (63.5 ac)
4 overall decrease in native plant community cover and 38% (1.7 ac) decrease in wetland
5 community cover. The diversity of native community types under this alternative would decrease
6 and is similar to that under Alternative A.

7
8 Repeated extended high flows can remove tamarisk (Stevens and Waring 1986a;
9 Kearsley and Ayers 1999), resulting in a decrease in tamarisk-dominated communities, although
10 less of a decrease than under Alternative A. Because the decrease in native community types
11 modeled (63.5 ac) is greater than the decrease in tamarisk (45.7 ac), the native to nonnative ratio
12 under this alternative decreases 4% and is lower than under Alternative A.

13
14 Growing-season extended low flows can result in wetlands becoming replaced by
15 arrowweed (Porter 2002), and non-growing seasons without extended high or low flows
16 combined with growing-season extended low or extended high flows allow arrowweed to
17 become established on bare sand (Waring 1995). Based on results of modeling arrowweed-
18 dominated communities would be expected to increase 25% (44.0 ac) under this alternative,
19 similar to the increase under Alternative A.

20
21 The model results for each of the metrics are presented in Table 4.6-3 and shown in
22 Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows
23 (result in slightly more growing-season extended high flows), which result in a slightly greater
24 decrease in native community types, and TMFs, which have little effect on results, and HFEs,
25 which when absent result in a smaller decrease in native community types, a greater decrease in
26 tamarisk, and a greater increase in arrowweed (arrowweed establishment on bare sand is slowed
27 by fall HFEs; Waring 1995).

28
29 In summary, Alternative E would result in an adverse change associated with a decrease
30 in native cover (20% overall decrease in native plant community cover, 38% decrease in wetland
31 community cover; both decreases greater than under Alternative A), decrease in native diversity
32 (2%, similar to Alternative A), decrease in the ratio of native to nonnative community types (4%
33 decrease in ratio, a lower ratio than under Alternative A; 45.7 ac decrease in tamarisk, less of a
34 decrease than under Alternative A), and an increase in arrowweed cover (25%, similar to
35 Alternative A). These adverse effects could be less than anticipated depending on the effects of
36 the tamarisk leaf beetle in the area and the non-flow vegetation restoration experiment. Several
37 special status species could be impacted as a result of the decrease in wetland community cover.
38 The old high water zone would continue narrowing. Although the non-flow vegetation
39 restoration experiment may decrease these adverse effects to some extent, it is expected that
40 Alternative E would result in a movement away from the riparian vegetation resource goal over
41 the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

42
43

1 **4.6.3.6 Alternative F**
2

3 This alternative includes a much greater frequency of spring and fall HFEs than
4 Alternative A and any other alternative (see Section 4.2). Alternative F also features higher
5 volumes than Alternative A in April, May, and June, and lower volumes than Alternative A in
6 other months, with low flows from July through January. This alternative has a far greater
7 number of extended low flows than Alternative A, few seasons without extended high or low
8 flows, and frequent growing-season extended high flows, with slightly fewer extended high
9 flows compared to Alternative A.

10
11 Frequent extended high flows would result in a decrease in native community types,
12 including wetlands, with there being more (statistically significant) of a decrease than
13 Alternative A. Growing-season extended high flows can contribute to the loss of New High
14 Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and Waring
15 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. Extended low flows
16 during the growing season contribute to the shifting of wetland communities to tamarisk or
17 arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002). A greater frequency of HFEs,
18 very few seasons without extended high or low flows, and far more extended low flows would
19 result in lack of establishment of native community types, including wetlands
20 (Ralston et al. 2008; Waring 1995; Anderson and Ruffner 1987). The establishment of shrub
21 wetland communities on bare sand can be slowed by growing-season extended low or high flows
22 or HFEs (Stevens and Waring 1986a; Porter 2002). Extended low flows contribute to wetlands
23 becoming replaced by arrowweed (Porter 2002). This is supported by modeling results which
24 indicate a 30% (95.0 ac) overall decrease in native plant community cover and 86% (4.0 ac)
25 decrease in wetland community cover. Alternative F results in a greater loss of wetlands than any
26 other alternative due to the frequent extended high flows, the far greater number of extended low
27 flows, and the small number of seasons without extended high or low flows. The diversity of
28 native community types under this alternative is expected to decrease 9% and is lower
29 (statistically significant) than that under Alternative A and lower than any other alternative,
30 primarily due to the large decreases in wetland community types.

31
32 Growing-season extended low flows resulting from low steady flows from July through
33 October can contribute to the shifting of wetland and arrowweed communities to tamarisk
34 (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002) as wetlands
35 dry and arrowweed colonizes former wetland areas. Wetlands transition to tamarisk with
36 growing-season extended high flows in combination with extended low flows (Sher et al. 2000;
37 Mortenson et al. 2012). The frequent extended high flows often shift all states to bare sand,
38 which then shifts to tamarisk. Spring HFEs and growing-season extended high and low flows
39 promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000;
40 Porter 2002; Mortenson et al. 2012). In addition, tamarisk communities are not expected to
41 transition to other community types under this alternative, and as a result, this alternative would
42 result in the greatest increase in tamarisk of any alternative (230.7 ac). Because of the large
43 decrease in native community types (95.0 ac), the native to nonnative ratio under this alternative
44 decreases 62% and is lower (statistically significant) than under Alternative A.
45

1 Extended low flows contribute to wetlands becoming replaced by arrowweed
2 (Porter 2002). Extended low flows combined with extended high flows result in the
3 establishment of arrowweed on bare sand (Waring 1995). However, extended high flows
4 followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk
5 (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Based on results of modeling,
6 Alternative F would result in a 13% (22.2 ac) decrease in the arrowweed community type, with
7 arrowweed cover being lower (statistically significant) than under Alternative A. Note that this
8 reduction is considered a benefit because of the invasive nature of this species and associated
9 impacts on meeting sediment resource objectives and recreation goals for camping.

10
11 The model results for each of the metrics are presented in Table 4.6-3 and shown in
12 Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

13
14 In summary, Alternative F would result in a beneficial change associated with a decrease
15 in arrowweed (13%, lower cover than under Alternative A). This benefit could be greater than
16 anticipated depending on the effects of the non-flow vegetation restoration experiment.
17 However, Alternative F is also expected to result in adverse effects associated with a decrease in
18 native cover (30% overall decrease in native plant community cover, 86% decrease in wetland
19 community cover; both decreases greater than under Alternative A), decrease in native diversity
20 (9%, lower diversity than under Alternative A), and decrease in the ratio of native to nonnative
21 community types (62% decrease in ratio, a lower ratio than under Alternative A; 230.7 ac
22 increase in tamarisk, greater cover than under Alternative A). Several special status species could
23 be impacted as a result of the decrease in wetland community cover. There is a small potential
24 for impacts on active floodplain and Lake Mead shoreline special status species and benefit to
25 inactive floodplain special status species. The Old High Water Zone would continue narrowing,
26 although annual spring HFEs could result in higher survival rates than Alternative A of plants at
27 lower elevations of the zone. Although the non-flow vegetation restoration experiment may
28 decrease these adverse effects to some extent, it is expected that Alternative F would result in a
29 movement away from the riparian vegetation resource goal over the LTEMP period. The
30 tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

31 32 33 **4.6.3.7 Alternative G**

34
35 This alternative includes sediment-triggered spring and fall HFEs, extended-duration fall
36 HFEs (up to 336-hr, 45,000-cfs releases), and proactive spring HFEs in high volume years. Equal
37 monthly volumes and steady flows conserve more sediment, and therefore result in more
38 triggered HFEs. As a result, Alternative G has a far greater frequency of fall and spring HFEs
39 compared to Alternative A and most other alternatives (Section 4.2). Because monthly volumes
40 would be approximately equal, this alternative has a far greater number of extended low flows
41 and fewer extended high flows compared to Alternative A.

42
43 Occasional extended high flows (although less frequent than under Alternative A) would
44 result in a decrease in native community types through scouring and drowning, including
45 wetlands, with there being more (statistically significant) of a decrease than under Alternative A.
46 A greater frequency of HFEs and far more extended low flows would result in lack of

1 establishment of native community types; consequently, native community types including
2 wetlands decrease under this alternative (Ralston et al. 2008; Waring 1995; Anderson and
3 Ruffner 1987), with the decrease being greater (statistically significant) than under
4 Alternative A. Extended low flows during the growing season contribute to the shifting of
5 wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012;
6 Porter 2002), and the establishment of shrub wetland communities on bare sand can be slowed
7 by growing-season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This
8 is supported by modeling results which indicate a 29% (93.7 ac) overall decrease in native plant
9 community cover and 58% (2.6 ac) decrease in wetland community cover. The diversity of
10 native community types under this alternative would be expected to decrease 3%, and would be
11 lower than that under Alternative A, primarily due to the large decreases in the wetland
12 community types.

13
14 Growing-season extended low flows along with an extended high flow can contribute to
15 the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000;
16 Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). Growing-season extended low
17 flows promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000;
18 Porter 2002). Spring HFEs in combination with growing-season extended low flows can also
19 contribute to tamarisk establishment on bare sand (Stevens and Waring 1986a; Porter 2002;
20 Mortenson et al. 2012) or spring HFEs in combination with a growing-season extended high
21 flow (Sher et al. 2000; Mortenson et al. 2012). Consequently, tamarisk-dominated communities
22 would be expected to increase under Alternative G, a 46.4 ac increase based on results of
23 modeling. Because of the large decrease in native community types (93.7 ac), the native to
24 nonnative ratio under this alternative would decrease (40% decrease) a lower ratio (statistically
25 significant) than under Alternative A.

26
27 Extended low flows can contribute to wetlands becoming replaced by arrowweed
28 (Porter 2002), and extended low flows combined with extended high flows can result in the
29 establishment of arrowweed on bare sand (Waring 1995). However, extended high flows
30 followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk
31 (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002), and growing-season extended high
32 flows contribute to the loss of arrowweed, resulting in bare sand (Kearsley and Ayers 1999;
33 Ralston 2010). Based on the results of modeling, Alternative G would result in a 11% (20.1 ac)
34 decrease in the arrowweed community type, with arrowweed cover being significantly lower
35 (statistically significant) than for Alternative A. Note that this reduction is considered a benefit
36 because of the invasive nature of this species and associated impacts on meeting sediment
37 resource objectives and recreation camping goals.

38
39 The model results for each of the metrics are presented in Table 4.6-3 and shown in
40 Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

41
42 In summary, Alternative G would result in a beneficial change associated with a decrease
43 in arrowweed (11%, lower cover than under Alternative A). This benefit could be greater than
44 anticipated depending on the effects of the non-flow vegetation restoration experiment.
45 However, Alternative G is also expected to result in adverse effects associated with a decrease in
46 native cover (29% overall decrease in native plant community cover, 58% decrease in wetland

1 community cover; both decreases greater than under Alternative A), decrease in native diversity
2 (3% decrease in native diversity over the LTEMP period, lower than under Alternative A), and
3 reduction in the ratio of native to nonnative community types (40% decrease in ratio, a lower
4 ratio than under Alternative A; 46.4 ac increase in tamarisk, greater cover than under
5 Alternative A). Several special status species could be impacted as a result of the decrease in
6 wetland community cover. There is a small potential for impacts on active floodplain special
7 status species. The Old High Water Zone would continue narrowing, although more spring HFES
8 than Alternative A could result in higher survival rates of plants at lower elevations of the zone.
9 Although the non-flow vegetation restoration experiment may decrease these adverse effects to
10 some extent, it is expected that Alternative G would result in a movement away from the riparian
11 vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to
12 reducing the increase in tamarisk.

15 4.7 WILDLIFE

17 This section addresses the effects of the
18 LTEMP alternatives on wildlife, including
19 special status species.

22 4.7.1 Analysis Methods

24 Models of the effects of alternatives on
25 wildlife populations were not available for use
26 in this analysis. This is, in part, a reflection of
27 the relatively limited amount of quantitative
28 data available on wildlife of Glen and Grand
29 Canyons, which would serve as the basis of
30 such models. Impact assessments are based on previous studies of wildlife in the project area and
31 on the assessments conducted for aquatic ecology (Section 4.5) and vegetation (Section 4.6),
32 because these assessments reflect impacts on terrestrial wildlife habitat and food production upon
33 which wildlife species depend.

35 Impacts of LTEMP alternatives were evaluated for the following wildlife species groups
36 (impacts on fish and other aquatic species are discussed in Section 4.5):

- 38 • Terrestrial invertebrates,
- 39
- 40 • Amphibians and reptiles,
- 41
- 42 • Birds,
- 43
- 44 • Mammals, and
- 45
- 46 • Special status species.

Issue: How do alternatives affect wildlife species in the project area?

Impact Indicators:

- Change in riparian and wetland wildlife habitats
- Change in aquatic habitats and food base used by wildlife
- Direct effects of HFES and other flow and non-flow actions on wildlife

1 Impacts of each alternative on these species groups were evaluated based on the
2 following impact indicators:

- 3
- 4 • Change in riparian and wetland wildlife habitats,
- 5
- 6 • Change in aquatic habitats and food base, and
- 7
- 8 • Direct effects of HFEs and other flow and non-flow actions on wildlife.
- 9

10 Other factors that could contribute to impacts on wildlife species and their habitats, such
11 as climate change, defoliation of tamarisk by the tamarisk leaf beetle (*Diorhabda* spp.), noise,
12 and uranium mining, are addressed as cumulative impacts (in Section 4.17.3.6).

15 **4.7.2 Summary of Impacts**

16

17 As described in Section 3.7, terrestrial wildlife populations in Glen and Grand Canyons
18 are influenced by the availability of suitable habitat, food, and water resources. Of most
19 importance for the analysis of the effects of LTEMP alternatives are those species dependent on
20 riparian, wetland, and aquatic habitats, because these habitats could be directly and indirectly
21 affected by LTEMP alternatives. Habitats above the riparian zone (mostly desert scrub) and the
22 wildlife that inhabit those areas would be unaffected by LTEMP alternatives.

23

24 Water release patterns associated with both daily and monthly base operations, and
25 experimental elements, particularly HFEs, are important factors that determine the coverage and
26 characteristics of riparian vegetation and wetlands. Section 4.6 describes the anticipated changes
27 in the characteristics of riparian vegetation communities over the LTEMP period; however, the
28 anticipated impacts of the alternatives on vegetation relate to transitions among plant community
29 types, not to increases or decreases in the amount of riparian and wetland vegetation coverage.
30 None of the alternatives are expected to result in important structural changes in riparian habitat
31 or overall riparian habitat coverage that could have population-level effects on terrestrial wildlife
32 species. As noted in Section 4.5, there has been a net increase in vegetation since construction of
33 the dam and none of the alternatives are expected to reverse these gains. In addition, many of the
34 terrestrial wildlife species that occur in Glen and Grand canyons utilize a variety of terrestrial
35 habitats and are not solely dependent on riparian habitat in general, or on the specific types of
36 riparian vegetation that occur along the river. These factors reduce the potential for impacts of
37 LTEMP alternatives on terrestrial wildlife.

38

39 Direct impacts of LTEMP alternatives on terrestrial wildlife species are possible, but
40 these are likely to be short term. Although HFEs could displace less mobile species such as
41 invertebrates, amphibians, and reptiles (Reclamation 2011b), these species can quickly
42 recolonize disturbed areas from adjacent areas; most vertebrate animals that occupy riparian
43 habitats are mobile enough to move in response to fluctuations in flow, and would return shortly
44 after the HFE is over.

45

1 A summary of impacts of the LTEMP alternatives on various wildlife groups is presented
2 in Table 4.7-1 and discussed below.
3

4 5 **4.7.2.1 Terrestrial Invertebrates** 6

7 Table 4.7-1 summarizes the potential effects of LTEMP alternatives on terrestrial
8 invertebrates. Invertebrates contribute to the diversity of the riparian corridor of the Colorado
9 River and perform important ecological functions as decomposers, herbivores, predators, and
10 pollinators. In addition, this diverse community of animals is an important component of the prey
11 base of insectivorous vertebrates including fish, frogs, toads, lizards, snakes, songbirds, small
12 mammals, and bats.
13

14 Most invertebrates in the riparian zone obtain their food from terrestrial sources, but the
15 diets of some species (e.g., ground beetles, ants, and spiders) are also subsidized by emerging
16 aquatic insects or by drifting aquatic organisms that become stranded in the varial zone
17 (Paetzold et al. 2006). Some changes in the characteristics of vegetation communities
18 (e.g., changes in diversity) and aquatic habitats may cause localized changes in terrestrial
19 invertebrates (Anderson, B.W. 2012). Terrestrial invertebrates in the riparian zone recovered
20 from the impacts of natural annual historic flood events, and are expected to recover quickly
21 from HFEs (Reclamation 2011b). None of the LTEMP alternatives are expected to result in long-
22 term population-level changes to terrestrial invertebrates.
23

24 Differences in the monthly and daily flow patterns of alternatives could affect the
25 production of insects with aquatic and terrestrial life stages (e.g., blackflies, midges, and
26 dragonflies) by affecting the stability of nearshore habitats and the amount of wetted area that
27 supports these insects. Alternatives with more stable flows (Alternatives C, F, and G) and those
28 with more even monthly release volumes (Alternatives C, D, E, and G) are expected to have
29 higher production of these insects because of greater habitat stability; however, any differences
30 among alternatives are expected to be relatively small (Section 4.5). The year-round steady flows
31 of Alternative G are likely to result in the greatest production of these insects, and experimental
32 steady weekend flows under Alternative D also target increased production and diversity.
33 Although these experimental flows have not been tested, on a conceptual basis, providing
34 steadier flows during important production months should produce more insects.
35

36 Experimental actions being considered under different alternatives also could adversely
37 affect or benefit terrestrial invertebrates in the Colorado River corridor. Experimental vegetation
38 restoration activities (common to all alternatives) would remove low-value nonnative plant
39 species and attempt to reestablish native species that could be of greater value to terrestrial
40 invertebrates. Low summer flows under Alternatives C, D, E, and F and TMFs under
41 Alternatives B, C, D, E, and G could adversely affect aquatic macroinvertebrate production on
42 temporarily exposed substrates, and this could in turn affect the production of aquatic insects
43 with terrestrial life stages. Low summer flows have the potential to have a greater impact than
44 TMFs on these insects because the flows would last for a 3-month period during the growing
45 season while the low flows of TMFs would be of
46

1 **TABLE 4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife**

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts on wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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 compared to Alternative A, however hydropower improvement flows would cause a greater decline of wetland habitat.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Increased production of aquatic insects, but accompanying benefits may be offset by higher within-day flow fluctuations.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. 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 compared to Alternative A.

4-189

2
3

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Terrestrial invertebrates	No change from current conditions.	Similar to Alternative A, but potentially lower production of insects with aquatic and terrestrial life stages due to higher daily flow fluctuations. No effect on other terrestrial invertebrates.	Potential increase in production of insects with aquatic and terrestrial life stages compared to Alternative A due to more uniform monthly flows from December through August, lower daily range in flows. No effect on other terrestrial invertebrates.	Potential increase in production of insects with aquatic and terrestrial life stages compared to Alternative A due to more uniform monthly flows; experimental steady weekend flows may also increase insect production and diversity. No effect on other terrestrial invertebrates.	Similar to Alternative A. Potential slight increase in production due to more uniform monthly flows, but any increase could be offset by higher within-day flow fluctuations. No effect on other terrestrial invertebrates.	Potential increase in production of insects with aquatic and terrestrial life stages compared to Alternative A resulting from steady flows and relatively high spring flows. No effect on other terrestrial invertebrates.	Similar to Alternative F, but year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest production of insects with aquatic and terrestrial life stages of all alternatives. No effect on other terrestrial invertebrates.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians and reptiles	Negligible impact on amphibians and reptiles; some decrease in wetland habitat from current condition, but no change in the stability of nearshore habitats that support adult and early life stages of amphibians and serve as food production areas for amphibians and reptiles. HFES could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A, but potentially lower insect production due to higher daily flow fluctuations. Second lowest wetland loss of any alternative. Hydropower improvement flows would have larger adverse effects on wetlands (similar to Alternative C) and food production than Alternative A. HFES could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to reduced daily fluctuations. Second highest wetland loss of any alternative. Increased number of HFES could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to relatively even monthly release volumes; experimental steady weekend flows may increase insect production and diversity. Lowest wetland loss of any alternative. Increased number of HFES could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Negligible impact, similar to Alternative A.	Benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to steady flows. Highest wetland loss of any alternative. Increased number of HFES could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative F, but year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives. Third highest wetland loss of any alternative. Increased number of HFES could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect terrestrial birds over the long term. HFEs would occur outside of the breeding season of most birds.	Similar to Alternative A, but larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on insect-eating birds and waterfowl using nearshore areas. HFEs would occur outside of the breeding season of most birds.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to reduced daily fluctuations. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Similar to Alternative A.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to steady flows. Annual 45,000 cfs spike flow would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to steady flows and even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.
Mammals	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect mammals over the long term. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A, but larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on semi-aquatic mammals and other mammals using nearshore areas. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A for semi-aquatic mammals and other mammals using nearshore areas due to reduced daily fluctuations. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A for semi-aquatic mammals and other mammals using nearshore areas due to even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A.	Similar to Alternative C.	Benefit compared to Alternative A for semi-aquatic mammals and other mammals using nearshore areas due to steady flows and even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

1 short duration (less than 1 day). Mechanical removal of trout should have no effect on terrestrial
2 invertebrates.

3
4 In summary, none of the LTEMP alternatives are expected to produce changes in riparian
5 habitats that would result in noticeable or measurable changes in invertebrates with only
6 terrestrial life stages. However, alternatives with reduced fluctuations (Alternatives C, D, F, and
7 G) or more even monthly release volumes (Alternatives C, D, E, and G) would have greater
8 nearshore habitat stability, and could result in an increase in the production of insects with both
9 aquatic and terrestrial life stages. Section 4.7.3 addresses the potential impacts on invertebrates
10 under each LTEMP alternative.

11 12 13 **4.7.2.2 Amphibians and Reptiles**

14
15 Table 4.7-1 summarizes the potential effects of LTEMP alternatives on amphibians and
16 reptiles. Glen Canyon Dam operations may affect amphibians (including their aquatic larval
17 stages) and reptiles along the Colorado River corridor, primarily through alterations of riparian
18 and wetland habitats and effects on aquatic insect production (Dettman 2005). The effects of
19 alternatives on amphibians (frogs and toads) could result from potential changes to wetland
20 habitat and nearshore habitat that supports both adult and early life stages and serves as
21 production areas for aquatic invertebrate prey. The effects of alternatives on reptiles (snakes and
22 lizards) could result from potential changes in riparian vegetation and terrestrial invertebrate prey
23 production. In addition, raised water levels from HFEs may drown some amphibians and reptiles
24 that are unable to escape the rising water (Dettman 2005), or flood habitats used by amphibians
25 and reptiles.

26
27 Amphibian and reptile populations along the river have increased under the modified
28 Colorado River flow regime created by operation of Glen Canyon Dam (Section 3.7.2).
29 Operations since completion of the dam have reduced the magnitude of spring floods and
30 subsequently allowed an increase in riparian vegetation colonizing areas previously scoured by
31 annual floods, and allowing the formation of wetlands under variable daily flows, but more
32 consistent monthly flows (Reclamation 1995). Effects of alternatives on these habitats and the
33 amphibians and reptiles supported by them are expected to be relatively small compared to these
34 larger changes from pre-dam conditions.

35
36 Amphibians could be affected by the predicted decreases in wetland habitat area over the
37 20-year LTEMP period. Wetland area along the river corridor downstream of Glen Canyon Dam
38 is limited (approximately 5 ac), making any loss potentially important for species dependent on
39 wetland areas. Based on vegetation modeling presented in Section 4.6, wetland habitat is
40 expected to decline over the LTEMP period under all alternatives, but impacts would be greater
41 under alternatives with steadier flows (Alternatives C, F, and G) than alternatives with higher
42 fluctuations (Alternatives A, B [except with experimental implementation of hydropower
43 improvement flows], D, and E), which provide daily watering of habitats in the varial zone.

44
45 Section 4.6 describes some changes in the characteristics of riparian vegetation
46 communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are

1 expected to result in important structural changes in riparian habitat or vegetation productivity
2 that could affect amphibians or reptiles over the long term. As discussed in Section 4.7.2.1,
3 invertebrates with only terrestrial life stages are not expected to be affected differentially by
4 alternatives, and those with both aquatic and terrestrial life stages are expected to benefit under
5 certain alternatives (alternatives with lower within-day fluctuations, such as Alternatives C, F,
6 and G, or more even monthly release volumes, such as Alternatives C, D, E, and G). Lower
7 fluctuations would also result in potential benefits for the survival of amphibian eggs and
8 tadpoles; however, as discussed in the previous paragraph, these alternatives also support less
9 wetland habitat, which is important to amphibians. Lizard and snakes would benefit less from
10 increases in aquatic-based food production because these reptiles are less dependent on these
11 food sources than are amphibians.

12
13 In addition to these habitat and food-based impacts, HFEs can directly affect amphibians
14 by disrupting breeding activities and by flushing egg masses and tadpoles from backwaters
15 depending on the time of year in which they occur. Breeding and egg deposition occurs between
16 April and July, with metamorphosis to adult occurring between June and August (Dettman
17 2005). Thus, any HFEs conducted between April and August (e.g., sediment-triggered spring
18 HFEs or proactive spring HFEs) are likely to result in some disruption of reproduction and/or
19 mortality (Reclamation et al. 2002). Rising waters have the potential to trap lizards and snakes
20 that are resident below the elevation of HFE flows and drown them or their buried eggs (Warren
21 and Schwalbe 1985). In addition, possible reductions in riparian vegetation (e.g., from scouring)
22 and direct mortality of prey items could lead to a decrease in prey availability (Dettman 2005;
23 Reclamation et al. 2002). These effects are expected to be temporary and not to result in long-
24 term effects on amphibian and reptile populations, because the area affected by scour would be
25 small (below the elevation of 45,000 cfs flows) relative to total habitat availability, and
26 recolonization of disturbed areas by vegetation and amphibian and reptile populations in adjacent
27 unaffected areas is expected to occur. Prior to construction of the dam, flooding was an annual
28 natural event in the Grand Canyon from which amphibians and reptiles recovered. Thus, they are
29 expected to quickly recover from individual HFEs (Reclamation 2011b).

30
31 Other experiments being considered under different alternatives also could affect
32 amphibians and reptiles in the Colorado River corridor. Experimental vegetation restoration
33 activities (common to all alternatives) would remove low-value nonnative plant species and
34 attempt to reestablish native species that could be of greater value to amphibians and reptiles.
35 Activities associated with this restoration could disturb amphibians and reptiles in and adjacent
36 to restoration areas, but this should be temporary unless individuals were inadvertently killed.
37 Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E,
38 and G could adversely affect aquatic food base production on temporarily exposed substrates;
39 this could in turn affect amphibians and reptiles that consume aquatic invertebrates or terrestrial
40 life stages of aquatic insects. Low summer flows have the potential to have a greater impact than
41 TMFs on amphibians and reptiles because the flows would last for a 3-month period during the
42 growing season, while the low flows of TMFs would be of short duration (less than 1 day).
43 Mechanical removal of trout should have no effect on amphibians or reptiles.

44
45 In summary, none of the LTEMP alternatives are expected to produce changes in riparian
46 habitats that would affect amphibian and reptile populations. However, alternatives could

1 produce changes in nearshore aquatic and wetland habitats occupied by some amphibian and
2 reptile species, and those that serve as important food production areas for them (Table 4.7-1).
3 Alternatives C, D, F, and G would produce more stable flows, which would favor food
4 production in nearshore habitat areas, but these alternatives would provide less support for
5 wetlands than would alternatives with higher fluctuations (Alternatives A, B, and E). Direct
6 impacts from HFEs on amphibians and reptiles are expected to be negligible and temporary.
7 Periodic flooding is a natural phenomenon along rivers; amphibian and reptile species have
8 adapted to flooding and, from an ecosystem maintenance perspective, they are dependent on it.
9 Section 4.7.3 addresses the potential impacts on amphibians and reptiles under each LTEMP
10 alternative.

11 12 13 **4.7.2.3 Birds** 14

15 Riparian birds, many of which are protected under the Migratory Bird Treaty Act, have
16 increased along the river corridor downstream of Glen Canyon Dam in response to an increase in
17 riparian vegetation under dam operations (Brown et al. 1983; LaRue et al. 2001). In general,
18 birds that use the Grand Canyon corridor temporarily during migration are not affected by Glen
19 Canyon Dam operations; however, birds that breed or overwinter in the riparian zone can be
20 directly and indirectly affected by operations. Table 4.7-1 summarizes the potential effects of
21 LTEMP alternatives on birds.

22
23 Changes in riparian and wetland plant coverage can alter foraging and nesting habitats.
24 Even the loss of less desirable vegetation such as tamarisk may have potential negative effects on
25 bird species unless replaced promptly by native woody vegetation (Yard et al. 2004; see also
26 Section 4.17.3.6). The structural complexity of riparian vegetation (e.g., tree, shrub, and ground
27 vegetation layers) and the ecological function they provide is particularly important for many
28 nesting birds (Sogge et al. 1998). Section 4.6 describes some changes in the characteristics of
29 riparian vegetation communities over the LTEMP period, but none of the alternatives are
30 expected to result in significant structural changes in riparian habitat or vegetation productivity
31 that could affect bird populations over the long term.

32
33 Differences in the monthly and daily flow patterns of alternatives could affect nearshore
34 foraging areas used by waterfowl and wading birds. As discussed in Section 4.7.2.1, insects with
35 only terrestrial life stages are not expected to be affected differentially by alternatives, and those
36 with both aquatic and terrestrial life stages are expected to benefit under certain alternatives
37 (those with lower within-day fluctuations or more even monthly release volumes such as
38 Alternatives C, D, F, and G). These changes in food production could result in very minor
39 adverse impacts on birds, in part because most birds forage over broad areas that include habitats
40 outside of the river corridor.

41
42 In general, the potential for direct impacts of flows on birds would be greatest during the
43 nesting period when nests could be inundated. Impacts of normal operating flows (between
44 5,000 and 20,000 cfs) are expected to be negligible because few birds nest in these areas
45 (Sogge et al. 1998), and Brown and Johnson (1985) reported that flows up to 31,000 cfs do not
46 affect the nests of riparian birds. Only flows above the normal operating range, such as HFEs,

1 could affect nesting birds, and only if they occurred during the peak nesting period (May through
2 August) because active nests could be destroyed by these high flows. For shrub-nesting
3 songbirds such as Bell's vireo (*Vireo bellii*) and common yellowthroat (*Geothlypis trichas*),
4 inundation of the ground below nests begins to occur at flows of about 36,000 cfs, and nest
5 losses of 50% or more begin to occur from 40,000 to 62,000 cfs. These species can renest as long
6 as high waters do not persist (Brown and Johnson 1985). The nests of some ground-nesting
7 waterfowl species such as mallards (*Anas platyrhynchos*), gadwalls (*A. strepera*), and American
8 wigeon (*A. americana*) could be more susceptible to HFEs than those of songbirds that nest in
9 riparian vegetation, in part because these species breed earlier in the year when spring HFEs
10 would be implemented. Sediment-triggered spring and fall HFEs would occur outside of the
11 main nesting period for most birds, although proactive spring HFEs considered for testing under
12 Alternatives C, D, and G could occur during the nesting period (April through June). Alternative
13 F features an annual 45,000 cfs spike flow that would occur in May. HFEs outside of the nesting
14 period are expected to only temporarily displace birds within the flood zone, and they are
15 expected to use flooded areas once the high flows recede. Overall, riparian bird populations were
16 unaffected by prior floods, so no effects are expected from HFEs (Reclamation 2011b).

17
18 Waterfowl that winter in Glen and Grand Canyons would not be present during the
19 months when spring and fall HFEs would most likely occur (March through June and October or
20 November, respectively). Fall HFEs may have a short-term effect on foraging habitat and food
21 resources for early-arriving winter waterfowl.

22
23 Other experiments being considered under different alternatives also could adversely
24 affect or benefit birds in the Colorado River corridor. Experimental vegetation restoration
25 activities (common to all alternatives) would remove low-value nonnative plant species and
26 attempt to reestablish native species that could be of greater value to birds. Activities associated
27 with this restoration could disturb birds in and adjacent to restoration areas, but this should be
28 temporary unless nests were inadvertently destroyed. Low summer flows under Alternatives C,
29 D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food
30 base production on temporarily exposed substrates, which could in turn affect birds that consume
31 aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the
32 potential to have a greater impact than TMFs on birds because the flows would last for a 3-
33 month period during the growing season, while the low flows of TMFs would be of short
34 duration (less than 1 day). TMFs and trout removal in the Little Colorado River reach could have
35 a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*) and belted
36 kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. However, these
37 experimental trout control measures are only intended to be used in cases where trout recruitment
38 and population size is considered to be high, and annual implementation considerations include
39 consideration of impacts on other resources such as wildlife.

40
41 In summary, none of the LTEMP alternatives are expected to produce changes in aquatic
42 and riparian habitats that would result in long-term, population-level impacts on riparian bird
43 populations. However, alternatives could produce changes in nearshore habitats that could affect
44 waterfowl and wading birds; Alternatives C, D, F, and G would produce more stable nearshore
45 habitat for these species. Direct impacts from HFEs on birds would be minimal, mostly because
46 the timing of HFEs would occur outside of the peak breeding season. Under Alternatives C, D,

1 and G, proactive spring HFEs would occur in high-volume release years (≥ 10 maf); these could
2 occur during the peak nesting season (April through June) and result in the loss of some nests.
3 Alternative F also could affect nesting birds, because it features an annual 45,000-cfs spike flow
4 that would occur in May. Section 4.7.3 addresses the potential impacts on birds under each
5 LTEMP alternative.
6
7

8 **4.7.2.4 Mammals**

9

10 Table 4.7-1 summarizes the potential effects of LTEMP alternatives on mammals.
11 Section 4.6 describes changes in the riparian vegetation community types over the LTEMP
12 period, but these are not expected to result in important structural changes in riparian habitat or
13 vegetation productivity that could affect mammal populations over the long term. Differences in
14 the monthly and daily flow patterns of alternatives could have differential effects on the habitat
15 stability of nearshore areas used by semi-aquatic mammals and other mammals using nearshore
16 areas. As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages are not
17 expected to be affected differentially by alternatives and those with both aquatic and terrestrial
18 life stages are expected to benefit from alternatives with more stable flows. These changes in
19 food production are expected to result in very minor effects on insect-eating mammals, such as
20 shrews, mice, and bats. Riparian vegetation changes during the LTEMP period are not expected
21 to have adverse impacts on habitat or food resources for herbivorous mammals that occupy
22 riparian habitats.
23

24 HFEs may have direct impacts on some mammals. Less mobile species such as shrews,
25 mice, and other small mammals may drown but some individuals would be able to move upslope
26 away from flood waters. Recolonization of flooded areas would be expected to occur rapidly.
27 Loss of young mammals in ground nests could be destroyed, but multiple litters per year may
28 compensate for any losses from an individual HFE (Dettman 2005). No long-term population-
29 level impacts on these mammals are anticipated.
30

31 Along the Colorado River, American beavers (*Castor canadensis*) inhabit and raise their
32 young in bank dens, which they create near the water's edge; the lack of high flows allows them
33 to build their dens lower down in the banks. HFEs may drown young or adults in their bank dens
34 (Dettman 2005; Reclamation et al. 2002). HFEs affect muskrats (*Ondatra zibethicus*) similarly
35 (Reclamation 2011b). Young born prior to a spring or proactive spring HFE may drown if they
36 are located below the flood stage and are unable to leave the lodge. Fall HFEs are unlikely to
37 impact the American beaver or muskrat because they would be able to leave their dens and swim
38 to safety (Reclamation 2011b). These species regularly occur in riverine habitats subjected to
39 regular flood flows, and are adapted to these conditions both in terms of their ability to respond
40 to increases in flow and to recolonize areas affected by floods.
41

42 Large carnivores such as the cougar (*Puma concolor*) would experience minimal impacts
43 from dam operations because they generally have large ranges and can obtain prey from both
44 riparian and upland (desert) communities. Similarly, bighorn sheep (*Ovis canadensis*) and mule
45 deer (*Odocoileus hemionus*) are highly mobile and use a variety of habitats within the Grand
46 Canyon, including non-riparian habitats (Dettman 2005).

1
2 Other experiments being considered under different alternatives also could adversely
3 affect or benefit mammals in the Colorado River corridor. Experimental vegetation restoration
4 activities (common to all alternatives) would remove low-value nonnative plant species and
5 attempt to reestablish native species that could be of greater value to mammals. Activities
6 associated with this restoration could disturb mammals in and adjacent to restoration areas, but
7 this should be temporary unless individuals or nests were inadvertently destroyed. Low summer
8 flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could
9 adversely affect aquatic food base production on temporarily exposed substrates, and this could
10 in turn affect mammals that consume terrestrial life stages of aquatic insects. Low summer flows
11 have the potential to have a greater impact than TMFs on mammals because the flows would last
12 for a 3-month period during the growing season, while the low flows of TMFs would be of short
13 duration (less than 1 day). Mechanical removal of trout should have no effect on mammals.
14

15 In summary, none of the LTEMP alternatives are expected to produce changes in riparian
16 habitats that would affect mammal populations. Direct impacts from HFEs on mammals would
17 be negligible and temporary, and no long-term population-level impacts are expected.
18 Section 4.7.3 addresses the potential impacts on mammals under each LTEMP alternative.
19
20

21 **4.7.2.5 Special Status Species**

22
23 Eleven special status wildlife species, listed under the Endangered Species Act, Bald and
24 Golden Eagle Protection Act, or the State of Arizona, are known to occur or could occur along
25 the Colorado River corridor between Glen Canyon Dam and Lake Mead (Section 3.7). Potential
26 impacts on these species from LTEMP alternatives are summarized in Table 4.7-2 and discussed
27 below.
28

29 The effects of dam operations and HFEs under the LTEMP alternatives are discussed for
30 each special status species below. Other experiments being considered under different
31 alternatives also could adversely affect or benefit these species in the Colorado River corridor.
32 Experimental vegetation restoration activities (common to all alternatives) would remove low-
33 value nonnative plant species and attempt to reestablish native species that could be of greater
34 value to special status species. Activities associated with this restoration could disturb special
35 status birds in and adjacent to restoration areas, but this should be temporary unless nests were
36 inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under
37 Alternatives B, C, D, E, and G could adversely affect aquatic food base production on
38 temporarily exposed substrates, and this could in turn affect special status species that consume
39 aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the
40 potential to have a greater impact than TMFs on special status species because the flows would
41 last for a 3-month period during the growing season while the low flows of TMFs would be of
42 short duration (less than 1 day). TMFs

1 **TABLE 4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife Species**

Species and Status ^a	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Losses of habitat and individuals of Kanab ambersnail. Decrease in potential wetland habitat for northern leopard frog and Yuma clapper rail. Sediment-triggered spring HFEs could adversely affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat, but this benefit would not persist past 2020 when HFEs are discontinued. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A. Compared to Alternative A, similar decrease in wetland habitat for northern leopard frog and Yuma clapper rail, but greater potential decrease under hydropower improvement flows. Sediment-triggered spring HFEs could adversely affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population. Adverse impact due to greater wetland loss on northern leopard frog and Yuma clapper rail. Proactive spring HFEs may affect nests of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population. Least wetland loss of any alternative would benefit northern leopard frog and Yuma clapper rail. Proactive spring HFEs may affect nests of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency could inhibit rebound of the population. Similar wetland loss to Alternative A. Spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population. Adverse impact due to greater wetland loss on northern leopard frog and Yuma clapper rail. Annual extended-duration high flow in May could affect nests of southwestern willow flycatcher. Spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population. Adverse impact due to greater wetland loss on northern leopard frog and Yuma clapper rail. Proactive spring HFEs may affect nests of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.

4-199

TABLE 4.7-2 (Cont.)

Species and Status ^a	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Invertebrates</i>							
Kanab ambersnail (<i>Oxyloma haydeni kanabensis</i>) ESA-E; AZ-SGCN	No change from current conditions. The average of 5.5 HFEs and maximum of 14 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise through the early portion of the LTEMP period (HFEs would expire in 2020); some rebound between HFEs and after 2020 would be expected; no impacts would occur on the Elves Chasm population.	The average of 7.2 HFEs and maximum of 10 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the low frequency of HFEs would allow some rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 21.3 HFEs and maximum 40 HFEs could cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 19.3 HFEs and maximum 38 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 17.1 HFEs and maximum 30 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 38.1 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and the annual extended-duration high flow in May would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 24.5 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.

TABLE 4.7-2 (Cont.)

Species and Status ^a	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians							
Northern leopard frog (<i>Lithobates pipiens</i>) AZ-SGCN	Species may already be extirpated downstream of Glen Canyon Dam. Negligible change from current condition. Some decrease in wetland habitat, but no change in the stability of nearshore habitats that support adult and early life stages and serve as food production areas.	Similar to Alternative A, but potentially lower insect production due to higher daily flow fluctuations; hydropower improvement flows would have larger adverse effects on wetlands and food production than Alternative A.	Potential benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations, but these benefits could be offset by greater wetland losses.	Potential benefit compared to Alternative A due to lowest wetland habitat loss and an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations and relatively even monthly release volumes; experimental steady weekend flows may also increase insect production and diversity.	Negligible impact, similar to Alternative A.	Potential benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to steady flows, but these benefits could be offset by greater wetland losses.	Similar to Alternative F, but year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives. These benefits could be offset by greater wetland losses
Birds							
American peregrine falcon (<i>Falco peregrinus</i>) AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.

TABLE 4.7-2 (Cont.)

Species and Status ^a	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Bald eagle (<i>Haliaeetus leucocephalus</i>) BGEPA; AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.
California condor (<i>Gymnogyps californianus</i>) ESA-EXPN; AZ-SGCN	HFES may benefit the species by temporarily increasing the amount of beach habitat until 2020, when HFES expire.	Similar to Alternative A, but HFES would continue for the duration of the LTEMP period.	Increased number of HFES compared to Alternative A may produce long-term benefits associated with beach habitats.	Similar to Alternative C.			
Golden eagle (<i>Aquila chrysaetos</i>) BGEPA; AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.
Osprey (<i>Pandion haliaetus</i>) AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.

4-202

TABLE 4.7-2 (Cont.)

Species and Status ^a	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Southwestern willow flycatcher (<i>Empidonax traillii extimus</i>) ESA-E; AZ-SGCN	No change from current conditions. Sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August).	Same as Alternative A.	Proactive spring HFEs could occur in May or June and affect nests in riparian habitats, but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August). Experimental low summer flows could result in adverse effects on nesting habitat.	Proactive spring HFEs could occur in May or June and affect nests in riparian habitats, but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August). Experimental low summer flows could result in adverse effects on nesting habitat.	Same as Alternative A. Experimental low summer flows could result in adverse effects on nesting habitat.	Annual 45,000-cfs high flow would be implemented during the nesting season (May), but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August). Low steady flows in summer could result in adverse effects on nesting habitat.	Proactive spring HFEs could occur in May or June and affect nests in riparian habitats, but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August).
Western yellow-billed cuckoo (<i>Coccyzus americanus occidentalis</i>) ESA-T(DPS); AZ-SGCN	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.

TABLE 4.7-2 (Cont.)

Species and Status ^a	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Yuma clapper rail (<i>Rallus longirostris yumanensis</i>) ESA-E; AZ-SGCN	No change from current conditions. Sediment-triggered spring HFEs could affect nests in wetland areas.	Similar to Alternative A.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Relatively high wetland loss could adversely affect this species.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Lower wetland loss compared to others could benefit this species.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Wetland loss comparable to Alternative A.	Annual 45,000-cfs high flow in May increase potential to impact nests compared to Alternative A. Relatively high wetland loss could adversely affect this species.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Relatively high wetland loss could adversely affect this species.
Mammals							
Spotted bat (<i>Euderma maculatum</i>) AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.

^a AZ-SGCN = Arizona Wildlife Species of Greatest Conservation Need; BGEPA = Protected under the Bald and Golden Eagle Protection Act; ESA-E = Endangered Species Act-Endangered; ESA-EXPN = Endangered Species Act-Experimental Population, Non-Essential; ESA-T(DPS) = Endangered Species Act-Threatened (Distinct Population Segment).

4-204

1
2

1 and trout removal in the Little Colorado River reach could have a minor effect on osprey
2 (*Pandion haliaetus*) and bald eagle (*Haliaeetus leucocephalus*), because of the reduction in trout
3 numbers. However, these experimental trout control measures are only intended to be used in
4 cases when trout recruitment and population size is considered to be high, and annual
5 implementation considerations include consideration of impacts on other resources such as
6 special status species.

7
8 Section 4.7.3 addresses the potential impacts on the special status species under each
9 LTEMP alternative, including potential impacts of condition-dependent and experimental
10 elements of the alternatives.

11 12 13 **Kanab Ambersnail (*Oxyloma haydeni kanabensis*)**

14
15 Within the Grand Canyon, populations of the Kanab ambersnail occur at Vasey's
16 Paradise and Elves Chasm. Because the Elves Chasm population is located above the 100,000 cfs
17 stage (FWS 2008), this population would not be affected by any of the LTEMP alternatives. At
18 Vasey's Paradise, very little Kanab ambersnail habitat and only a few individuals occur below
19 the 25,000-cfs stage (Meretsky and Wegner 2000; Sorensen 2009). Most Kanab ambersnail
20 habitat is located above the 33,000 cfs stage (Reclamation 2011b). HFEs may scour or inundate
21 portions of Kanab ambersnail habitat (Kennedy and Ralston 2011). The November 1997 test
22 flow of 31,000 cfs scoured 1% (7 m²) of Kanab ambersnail habitat (FWS 2008). HFEs of
23 45,000 cfs cause a temporary loss of as much as 17% (119 m²) of Kanab ambersnail habitat
24 (FWS 2008). Surveys conducted after HFEs revealed no population-level declines in the Kanab
25 ambersnail population (Kennedy and Ralston 2011). Kanab ambersnails can survive up to
26 32 hours underwater in cold, well-oxygenated water (FWS 2011c); so as long as they are not
27 washed away, they could survive inundation from the short-term HFEs. The effects of extended-
28 duration HFEs (up to 250 hr in length) proposed under Alternatives C, D, and G, and the
29 extended-duration high flow in May under Alternative F are not known, but they could pose a
30 greater threat to Kanab ambersnail habitat within the area affected by 45,000-cfs flows.

31
32 Recovery of ambersnail habitat scoured by HFEs can take 2.5 years (Sorensen 2009).
33 Therefore, frequent HFEs or extended-duration HFEs may result in long-term loss of ambersnail
34 habitat that occurs below the 45,000-cfs flow level (FWS 2011c). However, the snails survived
35 and persisted through natural pre-dam floods and the 1983 flood (Reclamation 1995), which
36 were much larger in magnitude and duration than HFEs proposed under the LTEMP, so HFEs
37 may not represent a substantial threat to the persistence of the Kanab ambersnail (Kennedy and
38 Ralston 2011).

39
40 Section 4.7.3 addresses the potential impacts on the Kanab ambersnail under each
41 LTEMP alternative.

1 **Northern Leopard Frog (*Lithobates pipiens*)**
2

3 Only one population of northern leopard frogs, located within the Glen Canyon National
4 Recreation Area (GCNRA), has been recorded along the Colorado River between Glen Canyon
5 Dam and Lake Mead. However, individuals have not been observed at this location since 2004
6 (Drost 2005), and it is possible this population has been extirpated. If the species still occurs in
7 Glen Canyon, operations and experiments under the LTEMP alternatives could affect it by
8 affecting the extent of wetland habitat, production of terrestrial invertebrates, or the stability of
9 nearshore habitats potentially used by adults and early life stages. As discussed in
10 Section 4.6.2.2, alternatives could produce changes in nearshore aquatic and wetland habitats.
11 Alternatives C, D, F, and G would produce more stable flows, which would favor food
12 production in nearshore areas and provide higher quality habitats for adults and early life stages
13 of the leopard frog, but Alternatives C, F, and G would provide less support for wetlands than
14 would alternatives with higher fluctuations (Alternatives A, B, and E) or Alternative D, which
15 would result in the least wetland loss of any alternatives. Section 4.7.3 addresses the potential
16 impacts on the northern leopard frog under each LTEMP alternative.
17
18

19 **American Peregrine Falcon (*Falco peregrinus*)**
20

21 Any impacts on the American peregrine falcon from dam operations are likely to be
22 indirect, possibly through influences on the distribution and abundance of aquatic and terrestrial
23 macroinvertebrate populations, which in turn would influence the availability of prey such as
24 swifts, other songbirds, bats, and—in winter—waterfowl (Holmes et al. 2005). However, based
25 on the evaluations presented in Sections 4.7.2.1 (invertebrates) and 4.7.2.3 (birds), differences
26 among alternatives are expected to be small and not affect the abundance of food available to
27 peregrine falcons. No effects of alternatives on foraging habitats (riverine, riparian, and desert
28 areas) or roosting and nesting habitats (cliffs) are anticipated. Section 4.7.3 addresses the
29 potential impacts on the American peregrine falcon under each LTEMP alternative.
30
31

32 **Bald Eagle (*Haliaeetus leucocephalus*)**
33

34 Bald eagles migrate through and overwinter in Marble Canyon and the upper half of the
35 Grand Canyon. There is no evidence that bald eagle abundance is directly affected by river flows
36 (Holmes et al. 2005). During low river flows, bald eagles can capture and scavenge
37 proportionally more prey from isolated pools and nearshore habitats. Inundation of these habitats
38 during high flows reduces or eliminates prey availability (Brown et al. 1989). During the winters
39 of 1990 and 1991, bald eagle foraging in the river, nearshore, and isolated pool habitats of the
40 Colorado River decreased to 0% at flows >20,000 cfs; foraging in adjacent creek habitat
41 increased to 100% (Brown et al. 1998). These observations demonstrate the ability of eagles to
42 respond to changes in foraging conditions by moving to more favorable areas nearby.
43 Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have
44 negligible effects on the ability of eagles to find and catch fish. TMFs and trout removal in the
45 Little Colorado River reach could have a minor effect on the bald eagle (*Haliaeetus*
46 *leucocephalus*), because of the reduction in trout numbers. However, these experimental trout

1 control measures are only intended to be used in cases when trout recruitment and population
2 size is considered to be high, and annual implementation considerations include consideration of
3 impacts on other resources such as special status species. Alternatives would have no effect on
4 habitats used for roosting (cliffs or trees). Wintering and migrant bald eagles are generally not
5 present during the months in which spring and fall HFEs would occur (Sogge et al. 1995).
6 Section 4.7.3 addresses the potential impacts on the bald eagle under each LTEMP alternative.
7
8

9 **California Condor (*Gymnogyps californianus*)**

10
11 California condors are opportunistic scavengers that consume carcasses of mammals,
12 birds, and fishes. Along the Colorado River corridor in Glen and Grand Canyons, they utilize
13 cliff locations for roosting, and beaches when drinking, resting, preening, and feeding
14 (Section 3.7). Individual HFEs are expected to temporarily increase beach habitat. Therefore,
15 Alternatives C, D, E, F, and G, which have the most HFEs, could provide a long-term benefit to
16 the California condor. Section 4.7.3 addresses the potential impacts on the California condor
17 under each LTEMP alternative.
18
19

20 **Golden Eagle (*Aquila chrysaetos*)**

21
22 Golden eagles are rare to uncommon residents and rare fall migrants throughout the
23 region (Gatlin 2013). None of the alternatives are expected to impact golden eagles, because they
24 nest on cliff edges and primarily feed on upland terrestrial wildlife. Indirect effects of LTEMP
25 alternatives on the abundance of mammals and other prey items within the narrow riparian zone
26 would be negligible, because the home range of the golden eagle can be over 300 km²
27 (NatureServe 2014). Section 4.7.3 addresses the potential impacts on the golden eagle under each
28 LTEMP alternative.
29
30

31 **Osprey (*Pandion haliaetus*)**

32
33 Ospreys typically occur along the Colorado River during their fall migration (August–
34 September), although a nesting pair recently fledged young near the dam (Section 3.7).
35 Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have
36 negligible effects on the ability of osprey to find and catch fish. TMFs and trout removal in the
37 Little Colorado River reach could have a minor effect on osprey (*Pandion haliaetus*), because of
38 the reduction in trout numbers. However, these experimental trout control measures are only
39 intended to be used in cases when trout recruitment and population size is considered to be high,
40 and annual implementation considerations include consideration of impacts on other resources
41 such as special status species. There would be no effect of alternatives on habitats used for
42 roosting (cliffs or trees) or nesting. Section 4.7.3 addresses the potential impacts on the osprey
43 under each LTEMP alternative.
44
45

1 **Southwestern Willow Flycatcher (*Empidonax traillii extimus*)**
2

3 The southwestern willow flycatcher nests and forages in habitats ranging from dense,
4 multi-storied riparian vegetation (such as cottonwood/willow stands with a mix of trees and
5 shrubs) to dense tamarisk stands with little layering of vegetation. However, changes in the
6 availability of suitable habitat may not necessarily translate into changes in the southwestern
7 willow flycatcher populations. Despite the abundance of woody riparian vegetation
8 (e.g., tamarisk) since construction of the Glen Canyon Dam, numbers of nesting southwestern
9 willow flycatchers in the Grand Canyon have declined since the 1980s and no nests have been
10 confirmed in the Grand Canyon since 2007 (Stroud-Settles et al. 2013).
11

12 The effect of HFEs on the southwestern willow flycatcher depends on whether the HFE
13 enhances or substantially reduces riparian habitat at potential breeding sites (Holmes et al. 2005).
14 High flows can scour and destroy riparian nesting habitat and foraging habitat. Alternatives C, D,
15 and G feature proactive spring HFEs in May or June that coincide with the nesting period of the
16 southwestern willow flycatcher. Alternative F features an annual 45,000-cfs spike flow and
17 extended-duration high flow in May. However, southwestern willow flycatchers nests in Grand
18 Canyon have typically been located above the elevation of 45,000-cfs flows (Gloss et al. 2005),
19 and thus may not be affected by the HFEs that would be implemented under the LTEMP
20 alternatives. In addition, sediment-triggered spring and fall HFEs would generally occur before
21 and after, respectively, the nesting period for the southwestern willow flycatcher
22 (Reclamation 2011b).
23

24 In addition to HFEs, lower flows during the May to August nesting period can have a
25 negative effect on southwestern willow flycatchers by drying riparian habitat
26 (Reclamation 2007d). Normal operations under most alternatives would have monthly average
27 flows of 10,000 cfs or more during the nesting period, except for Alternative F, with low steady
28 flows in summer through winter (July through February), and during the experimental
29 implementation of low summer flows under Alternatives C, D, and E. Under these three
30 alternatives, there is the potential for adverse effects on nesting habitat of this species. Only
31 under Alternative F are these impacts expected to be long term, because low summer flows
32 would occur annually under this alternative; low summer flow experiments under Alternatives C
33 and D would occur relatively infrequently and are not expected to have long-term effects on
34 nesting habitat.
35

36 Section 4.6 describes some changes in the characteristics of riparian vegetation
37 communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are
38 expected to result in important structural changes in riparian habitat or vegetation productivity
39 that could affect the southwestern willow flycatcher.
40

41 As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages, are not
42 expected to be affected differentially by alternatives, and those invertebrates with both aquatic
43 and terrestrial life stages are expected to benefit from alternatives with more stable flows. These
44 changes in food production are expected to result in very minor impacts on the southwestern
45 willow flycatcher.
46

1 In summary, only Alternative F is expected to produce changes in riparian habitats
2 (through regular low summer flows) that would affect the southwestern willow flycatcher. Direct
3 impacts from HFEs on nesting flycatchers would be minimal, mostly because the timing of HFEs
4 would be outside of the peak breeding season. Alternatives C, D, F, and G could have high flows
5 that occur during the peak nesting season; proactive spring HFEs under these three alternatives
6 would occur in high volume release years (≥ 10 maf); Alternative F features an annual 45,000-cfs
7 spike flow that would occur in May. Section 4.7.3 addresses the potential impacts on the
8 southwestern willow flycatcher under each LTEMP alternative.

9
10
11 **Western Yellow-Billed Cuckoo (*Coccyzus americanus occidentalis*)**
12

13 The western yellow-billed cuckoo occurs at a number of sites in the lower Grand Canyon,
14 near the Lake Mead delta where mature cottonwood forests are located. It requires structurally
15 complex riparian habitats with tall trees and a multi-storied vegetative understory; the large
16 caterpillars on which it feeds depend on cottonwoods and willows (Section 3.7). It is a rare
17 restricted transient in dense tamarisk thickets, with a few observations in the Lees Ferry reach
18 (Spence et al. 2011). Cottonwood/willow habitats that support the western yellow-billed cuckoo
19 are not expected to be affected by any of the LTEMP alternatives. Section 4.7.3 addresses the
20 potential impacts on the western yellow-billed cuckoo under each LTEMP alternative.

21
22
23 **Yuma Clapper Rail (*Rallus longirostris yumanensis*)**
24

25 The Yuma clapper rail inhabits marshes dominated by emergent plants. Generally, it is
26 associated with dense riparian and marsh vegetation dominated by cattails and bulrushes along
27 margins of shallow ponds with stable water levels (FWS 2014c). It is only a casual visitor to
28 marshy mainstem riparian habitats along the Colorado River downstream of Separation Canyon
29 (e.g., RM 227 and 246 and near Burnt Springs). The only confirmed nesting was reported in
30 1996. Its occurrence along the Colorado River in the affected area only occurred once suitable
31 habitat was created through dam construction (FWS 2014c). Other than predation, main threats
32 to the Yuma clapper rail include habitat destruction, primarily due to stream channelization and
33 drying and flooding of marshes resulting from water flow management (FWS 2014c). Spring
34 HFEs associated with LTEMP alternatives could cause inundation of Yuma clapper rail nests,
35 although nesting in the area may not occur or only rarely occur. All alternatives would have
36 spring HFEs, but these are expected to be less frequent for Alternatives A, B, and E (i.e., no
37 more than six for Alternative A and no more than 10 for Alternatives B and E). Spring HFEs
38 could occur every year under Alternatives C, D, F, and G. Section 4.7.3 addresses the potential
39 impacts on the Yuma clapper rail under each LTEMP alternative.

40
41
42 **Spotted Bat (*Euderma maculatum*)**
43

44 Most spotted bats occur in dry, rough desert shrublands or in pine forest communities.
45 These habitats are all located well above the river corridor and the area potentially affected by
46 Glen Canyon Dam operations. Their roost sites, including hibernacula, do not occur within the

1 area along the Colorado River affected by daily operations and HFEs. Only negligible adverse
2 effects on insects, the prey base for the spotted bat, would occur under any of the alternatives,
3 and the spotted bat can feed within upland areas that would not be impacted by LTEMP
4 operations. Thus, the spotted bat is not expected to be affected by any of the LTEMP
5 alternatives.

8 **4.7.3 Alternative-Specific Impacts on Wildlife**

10 This section describes alternative-specific impacts on wildlife, including special status
11 wildlife species. More detailed descriptions of the basis of impacts and supporting literature
12 citations for these impacts are presented in Section 4.6.2. Tables 4.7-1 and 4.7-2 summarize the
13 potential impacts of all alternatives on wildlife and special status wildlife species, respectively.

16 **4.7.3.1 Alternative A (No Action Alternative)**

18 Changes in riparian habitats under Alternative A would not result in noticeable or
19 measurable changes in invertebrates with only terrestrial life stages (Table 4.7-1). Because
20 aquatic food base productivity under Alternative A would be similar to current conditions
21 (Table 4.5-1), the contribution of aquatic insects with a terrestrial adult stage to the prey base for
22 wildlife that consume invertebrates will also remain unchanged.

24 Changes in riparian habitats under Alternative A would not affect amphibian, reptile,
25 bird, or mammal populations, but some amphibians and other wetland-dependent species could
26 be affected by wetland habitat decline expected under Alternative A (Section 4.7.2). The higher
27 flow fluctuations under Alternative A, which provide daily watering of habitats in the varial
28 zone, would limit wetland habitat loss. The effects of HFEs on reptiles and amphibians are
29 expected to be temporary and not result in long-term population effects because the area affected
30 would be small (below the elevation of 45,000-cfs flows) relative to total habitat availability, and
31 recolonization of disturbed areas by vegetation and by amphibians and reptiles following HFEs
32 are expected to occur rapidly from nearby unaffected areas.

34 No important structural changes in riparian habitat or vegetation productivity are
35 expected under Alternative A that could affect bird populations over the long term. HFEs under
36 Alternative A would occur outside the main nesting period of birds and are expected to only
37 temporarily displace birds within the flood zone. Fall HFEs may have a short-term effect on
38 foraging habitat and food resources for early-arriving winter waterfowl. Potential effects of
39 HFEs, although negligible, would not occur after 2020 under Alternative A.

41 No important structural changes in riparian habitat or vegetation productivity are
42 expected under Alternative A that could affect mammal populations over the long term. HFEs
43 could cause the direct loss of individuals belonging to less mobile species (e.g., small mammals).
44 Recolonization of flooded areas would be expected to occur rapidly. High reproductive rates of
45 most small mammals may compensate losses. HFEs, which would only occur through 2020, may
46 also cause the loss of some individual American beavers and muskrats, but long-term population-

1 level effects are not anticipated (Section 4.7.2.4). Minimal impacts are expected for bats and
2 large mammals.

3
4 Impacts of Alternative A on special status wildlife species are summarized in
5 Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon,
6 bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. HFEs could
7 cause losses of habitat and individuals in <20% of occupied habitat of the Vasey's Paradise
8 population of the Kanab ambersnail. Some rebound from the losses would occur between HFEs
9 or after 2020, when HFEs would expire. No impacts are expected on the Elves Chasm
10 population. A 28% decrease in wetland habitat may cause a change in potential habitat of the
11 northern leopard frog (which may already be extirpated downstream of Glen Canyon Dam) and
12 Yuma clapper rail (which has not been observed nesting in the area since 1996). Beach areas
13 created by individual HFEs may temporarily provide habitat used by the California condor, but
14 this would end after the HFE protocol expires in 2020. There would be no change from current
15 conditions for the southwestern willow flycatcher, because HFEs would mainly occur outside its
16 nesting period, and nesting is expected to occur above the elevation of HFEs.

17
18 In summary, under Alternative A, there would be little or no change from current
19 conditions for most wildlife species, including special status species, with the exception of a
20 potential adverse impact on amphibians and other species dependent on wetland habitats,
21 including the northern leopard frog and Yuma clapper rail. Beach areas created by individual
22 HFEs may temporarily provide habitat used by the California condor, but this would end after
23 the HFE protocol expires in 2020. There would be no impacts on other special status species.

24 25 26 **4.7.3.2 Alternative B**

27
28 Impacts of Alternative B on most terrestrial wildlife species would be similar to those
29 under Alternative A (Table 4.7-1), but there would be less impact on wetland habitat (i.e., 20%
30 decrease compared to 28% for Alternative A), except with the implementation of experimental
31 hydropower improvement flows, which could cause an 83% decrease in wetland habitat. There
32 would be slightly more HFEs under Alternative B (mean of 7.2 over the 20-year LTEMP period)
33 compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term
34 impacts on individuals of wildlife species that occur in areas inundated by HFEs, but these
35 impacts are not expected to result in long-term population-level effects. Higher daily flow
36 fluctuations would reduce nearshore habitat stability, especially with experimental hydropower
37 improvement flows, and could lower production of insects with aquatic and terrestrial life stages,
38 and adversely impact amphibians, waterfowl, semi-aquatic mammals, and other species that eat
39 insects or utilize nearshore areas. TMFs and trout removal in the Little Colorado River reach
40 could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and
41 belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental
42 trout control measures are only intended to be used in cases where trout recruitment and
43 population size is considered to be high, and annual implementation considerations include
44 consideration of impacts on other resources such as wildlife.

1 Impacts of Alternative B on special status wildlife species are presented in Table 4.7-2.
2 As under Alternative A, no impacts are anticipated on the following species: American peregrine
3 falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. Impacts
4 on the Kanab ambersnail would be similar to those under Alternative A. Larger negative wetland
5 and food production losses from hydropower improvement flows under Alternative B may have
6 greater effects on the northern leopard frog (which may be already be extirpated downstream of
7 Glen Canyon Dam) and the Yuma clapper rail (which has not been observed nesting in the area
8 since 1996). Beneficial impacts on the California condor from HFEs would be similar to those
9 under Alternative A, but would extend through the entire LTEMP period. There would be no
10 change from current conditions for the southwestern willow flycatcher, because HFEs would
11 occur outside its nesting period.

12
13 In summary, impacts of Alternative B on most terrestrial wildlife species would be
14 similar to those under Alternative A. Higher fluctuations under Alternative B would reduce
15 nearshore habitat stability and result in lower production of aquatic insects, which would
16 adversely impact species that eat insects or use nearshore areas. Experimental implementation of
17 hydropower improvement flows would result in adverse impacts on wetland habitat. There
18 would be some losses of habitat and individuals of Kanab ambersnail associated with HFEs
19 comparable to those under Alternative A. Beneficial impacts on the California condor of HFEs
20 would be similar to those under Alternative A, but would extend through the entire LTEMP
21 period. There would be no impacts on other special status species.

22 23 24 **4.7.3.3 Alternative C**

25
26 Impacts of Alternative C on most terrestrial wildlife species would be similar to those
27 under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of
28 wetland habitat (75% decrease compared to a 28% decrease), which could adversely affect
29 wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under
30 Alternative C (mean of 21.3 over the 20-year LTEMP period) compared to Alternative A (mean
31 of 5.5), which could increase the occurrence of short-term impacts on individuals of wildlife
32 species that occur in areas inundated by the HFEs; however, these impacts are not expected to
33 result in long-term population-level effects. More uniform monthly flows from December
34 through August under Alternative C compared to Alternative A may increase the production of
35 insects with aquatic and terrestrial life stages. In addition, an increase in habitat stability of
36 nearshore habitats compared to Alternative A may result from lower within-day fluctuations.
37 Both increases in insect production and nearshore habitat stability may benefit amphibians,
38 waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore areas.
39 TMFs and trout removal in the Little Colorado River reach could have a minor effect on
40 piscivorous birds such as great blue heron (*Ardea herodias*) and belted kingfisher (*Ceryle*
41 *alcyon*), because of the reduction in trout numbers. These experimental trout control measures
42 are only intended to be used in cases where trout recruitment and population size is considered to
43 be high, and annual implementation considerations include consideration of impacts on other
44 resources such as wildlife.

1 Impacts of Alternative C on special status wildlife species are presented in Table 4.7-2.
2 No impacts are anticipated on the following species: American peregrine falcon, bald eagle,
3 golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. More frequent HFEs and
4 extended-duration HFEs could adversely affect Kanab ambersnail and Yuma clapper rail.
5 Greater wetland habitat loss compared to Alternative A could adversely affect northern leopard
6 frog and Yuma clapper rail. Beach habitats created by more frequent HFEs could provide a long-
7 term benefit to the California condor. Proactive spring HFEs could occur in May and June,
8 affecting nests of the southwestern willow flycatcher, although it generally nests above the area
9 that may be inundated by 45,000-cfs flows. Sediment-triggered spring and fall HFEs would
10 occur outside its nesting period. Experimental low summer flows under Alternative C could have
11 an adverse effect on the quality of nesting habitat, but these experiments would occur relatively
12 infrequently and are not expected to have long-term effects on this habitat.
13

14 In summary, impacts of Alternative C on most terrestrial wildlife species would be
15 similar to those under Alternative A. More even monthly release volumes and lower fluctuations
16 under Alternative C would provide more stable nearshore habitats and result in higher production
17 of aquatic insects compared to Alternative A, potentially benefitting wildlife that eat insects and
18 use nearshore areas. Compared to Alternative A, Alternative C is expected to result in a minor
19 benefit to California condor (HFE effect on beaches), but minor adverse impacts on Kanab
20 ambersnail (HFE effects on habitat), northern leopard frog (wetland loss), Yuma clapper rail
21 (wetland loss and HFE effects on nests), and southwestern willow flycatcher (HFE effects on
22 nests and nesting habitats). There would be no impacts on other special status species.
23
24

25 **4.7.3.4 Alternative D (Preferred Alternative)**

26
27 Impacts of Alternative D on most terrestrial wildlife species would be similar to those
28 under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a smaller loss of
29 wetland habitat (16% decrease compared to a 28% decrease), which could benefit wetland-
30 dependent amphibians, reptiles, and birds; Alternative D has the lowest expected wetland loss
31 among all alternatives. There would be more HFEs (mean of 19.3 over the 20-year LTEMP
32 period) compared to Alternative A (mean of 5.5), which could increase the occurrence of short-
33 term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but
34 these impacts are not expected to result in long-term, population-level effects. More uniform
35 monthly flows throughout the year under Alternative D compared to Alternative A would
36 provide more stable aquatic habitats and may increase the production of insects with aquatic and
37 terrestrial life stages. Experimental weekend low flows may also increase production and
38 diversity of aquatic insects with terrestrial life stages. More stable nearshore habitat and insect
39 production may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that
40 eat insects or use nearshore habitats. TMFs and trout removal in the Little Colorado River reach
41 could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and
42 belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental
43 trout control measures are only intended to be used in cases where trout recruitment and
44 population size is considered to be high, and annual implementation considerations include
45 consideration of impacts on other resources such as wildlife.
46

1 Impacts of Alternative D on special status wildlife species are presented in Table 4.7-2.
2 No impacts are anticipated on the following species: American peregrine falcon, bald eagle,
3 golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. More frequent HFEs and
4 extended-duration HFEs compared to those under Alternative A could adversely affect Kanab
5 ambersnail and Yuma clapper rail. Lower wetland habitat losses under this alternative compared
6 to all others could benefit northern leopard frog and Yuma clapper rail. Potential benefits on the
7 California condor and adverse impacts on the southwestern willow flycatcher would be similar to
8 those under Alternative C.

9
10 In summary, impacts of Alternative D on most terrestrial wildlife species would be
11 similar to those under Alternative A. More even monthly release volumes under Alternative D
12 would provide greater nearshore habitat stability and result in higher production of aquatic
13 insects compared to Alternative A, potentially benefiting species that eat insects or use
14 nearshore areas. Experimental low weekend flows could also increase insect production.
15 Compared to Alternative A, Alternative D is expected to result in a minor benefit to California
16 condor (HFE effect on beaches), northern leopard frog (less wetland loss), and Yuma clapper rail
17 (less wetland loss), but minor adverse impacts on Kanab ambersnail (HFE effects on habitat),
18 Yuma clapper rail (HFE effects on nests), and southwestern willow flycatcher (HFE effects on
19 nests and nesting habitats). There would be no impacts on other special status species.

20 21 22 **4.7.3.5 Alternative E**

23
24 Impacts of Alternative E on most terrestrial wildlife would be similar to those under
25 Alternative A (Table 4.7-1). Compared to Alternative A, there would be a slightly greater loss of
26 wetland habitat under Alternative E (38% compared to a 28% decrease), which could adversely
27 affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under
28 Alternative E (mean of 17.1 over the 20-year LTEMP period) compared to Alternative A (mean
29 of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife
30 species that occur in areas inundated by the HFEs, but these impacts are not expected to result in
31 long-term population-level effects. More uniform monthly flows may increase production of
32 aquatic insects compared to Alternative A, but this may be offset by higher within-day flow
33 fluctuations, which would reduce habitat stability. TMFs and trout removal in the Little Colorado
34 River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea*
35 *herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers.
36 These experimental trout control measures are only intended to be used in cases where trout
37 recruitment and population size is considered to be high, and annual implementation
38 considerations include consideration of impacts on other resources such as wildlife.

39
40 Impacts of Alternative E on special status wildlife species are presented in Table 4.7-2.
41 No impacts are anticipated on the following species: northern leopard frog, American peregrine
42 falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. Impacts
43 on the Kanab ambersnail would be similar to Alternative A; however, more frequent HFEs may
44 prevent recolonization of impacted habitat over the long term. Potential beneficial impacts on the
45 California condor would be similar to those und Alternative C. Although HFEs would occur
46 outside its nesting period, experimental low summer flows under Alternative E could have an

1 adverse effect on the quality of nesting habitat, but these experiments would occur relatively
2 infrequently and are not expected to have long-term effects on this habitat.

3
4 In summary, impacts of Alternative E on most terrestrial wildlife species would be
5 similar to those under Alternative A. More even monthly flows under Alternative E would
6 provide greater nearshore habitat stability and result in higher production of aquatic insects, and
7 potential benefits for species that eat insects, but these benefits may be offset by higher within-
8 day fluctuations. Compared to Alternative A, Alternative E is expected to result in a minor
9 benefit for California condor (HFE effect on beaches), but minor adverse impacts on Kanab
10 ambersnail (HFE effects on habitat), northern leopard frog (wetland loss), Yuma clapper rail
11 (wetland loss and HFE effects on nests), and southwestern willow flycatcher (HFE effects on
12 nests and nesting habitats). There would be no impacts on other special status species.

13 14 15 **4.7.3.6 Alternative F**

16
17 Impacts of Alternative F on most terrestrial wildlife species would be similar to those
18 under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of
19 wetland habitat (86% decrease compared to a 28% decrease), which could adversely affect
20 wetland-dependent amphibians, reptiles, and birds. Wetland habitat loss would be higher for
21 Alternative F than for all other alternatives. There would be more HFEs under Alternative F
22 (mean of 38.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This
23 could increase the occurrence of short-term impacts on individuals of wildlife species that occur
24 in areas inundated by the HFEs, but these impacts are not expected to result in long-term
25 population-level effects; their frequency under this alternative would be comparable to the
26 frequency of annual floods in the pre-dam river. Steady flows and relatively high spring flows
27 under Alternative F compared to Alternative A may increase the production of insects with
28 aquatic and terrestrial life stages. This, in addition to an increase in habitat stability of nearshore
29 habitats compared to Alternative A, may benefit amphibians, waterfowl, semi-aquatic mammals,
30 and other species that eat insects or use nearshore areas.

31
32 Impacts of Alternative F on special status wildlife species are presented in Table 4.7-2.
33 No impacts are anticipated on the following species: American peregrine falcon, bald eagle,
34 golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. Impacts on the Kanab
35 ambersnail would be similar to those under Alternative A; however, more frequent HFEs may
36 prevent recolonization of impacted habitat over the long term. The relatively large decrease in
37 wetland habitat compared to other alternatives may adversely affect the northern leopard frog
38 and Yuma clapper rail. Potential benefits for the California condor would be similar to those
39 under Alternative C. The annual 1-day 45,000-cfs flow in May could affect nests of the
40 southwestern willow flycatcher, although it generally nests above the area that may be inundated
41 by 45,000-cfs flows. Annual low summer flows under Alternative F could have a long-term
42 adverse effect on the quality of nesting habitat of this species.

43
44 In summary, impacts of Alternative F on most terrestrial wildlife species would be
45 similar to those under Alternative A. Steady flows under Alternative F would provide greater
46 nearshore habitat stability and result in higher production of aquatic insects compared to

1 Alternative A, and would benefit species that eat insects or use nearshore areas. Compared to
2 Alternative A, Alternative F is expected to result in a minor benefit for California condor (HFE
3 effect on beaches), but minor adverse impacts on Kanab ambersnail (HFE effects on habitat),
4 northern leopard frog (wetland loss), Yuma clapper rail (wetland loss and HFE effects on nests),
5 and southwestern willow flycatcher (HFE and low summer flow effects on nests and nesting
6 habitats). There would be no impacts on other special status species.
7
8

9 **4.7.3.7 Alternative G**

10
11 Impacts of Alternative G on most terrestrial wildlife species would be similar to those
12 under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of
13 wetland habitat (58% decrease compared to a 28% decrease), which could adversely affect
14 wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under
15 Alternative G (mean of 24.5 over the 20-year LTEMP period) compared to Alternative A (mean
16 of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife
17 species that occur in areas inundated by the HFEs, but these impacts are not expected to result in
18 long-term, population-level effects. Year-round steady flows with little monthly variation would
19 produce the most stable nearshore habitats and greatest production of insects with aquatic and
20 terrestrial life stages. These conditions may benefit amphibians, waterfowl, semi-aquatic
21 mammals, and other species that eat insects or use nearshore habitats. TMFs and trout removal in
22 the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue
23 heron (*Ardea herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout
24 numbers. These experimental trout control measures are only intended to be used in cases where
25 trout recruitment and population size is considered to be high, and annual implementation
26 considerations include consideration of impacts on other resources such as wildlife.
27

28 Impacts of Alternative G on special status wildlife species are presented in Table 4.7-2.
29 No impacts are anticipated on the following species: American peregrine falcon, bald eagle,
30 golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. More frequent HFEs and
31 extended-duration HFEs could adversely affect Kanab ambersnail and Yuma clapper rail.
32 Greater wetland habitat loss compared to Alternative A could adversely affect northern leopard
33 frog and Yuma clapper rail. Beach habitats created by more frequent HFEs could provide a long-
34 term benefit to the California condor. Proactive spring HFEs could occur in May and June,
35 affecting nests of the southwestern willow flycatcher located in riparian habitats, although it
36 generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered
37 spring and fall HFEs would occur outside its nesting period.
38

39 In summary, impacts of Alternative G on most terrestrial wildlife species would be
40 similar to those under Alternative A. Steady flows under Alternative G would provide greater
41 nearshore habitat stability, result in higher production of aquatic insects, and benefit species that
42 eat insects or use nearshore areas. Compared to Alternative A, Alternative G is expected to result
43 in a minor benefit for California condor (HFE effect on beaches), but minor adverse impacts on
44 Kanab ambersnail (HFE effects on habitat), northern leopard frog (wetland loss), Yuma clapper
45 rail (wetland loss and HFE effects on nests), and southwestern willow flycatcher (HFE effects on
46 nests and nesting habitats). There would be no impacts on other special status species.

4.8 CULTURAL RESOURCES

4.8.1 Compliance with Federal Regulations

The National Historic Preservation Act (NHPA) of 1966 (as amended) requires that federal agencies take into account the effects of their undertakings on cultural resources. Historic properties, a subset of cultural resources, include archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties (TCPs), ethnographic resources, and museum collections. Historic properties include any archaeological sites, structures, buildings, districts, cultural landscapes, or TCPs that are determined to be eligible for listing in the *National Register of Historic Places* (NRHP). They also include locations and objects that are important for American Indian Tribes for maintaining their culture. (Cultural resources and TCPs of importance to Tribes are addressed in Section 4.9.)

Issue: How do the alternatives affect the preservation of cultural resources in Glen Canyon and Grand Canyon?

Impact Indicators:

- Erosion of terraces in Glen Canyon that support cultural resources
- Visitor effects on cultural resources
- Wind transport of sediment to protect resource-bearing terraces
- Flow effects on the Spencer Steamboat

The process for considering the effects of an undertaking on historic properties is identified in Section 106 of the NHPA, and an overview of the process is provided in Section 3.8 of this DEIS. For the proposed action, the area of potential effect (APE) is described in Chapter 3. Approximately 200 historic properties could be affected by the LTEMP. Most of these sites are situated on or within terraces located in the river corridor that are above the modern inundation zone, but that could receive windblown sediment from lower elevation areas that are regularly inundated by river flows or could be exposed by bank retreat or sediment depletion.

4.8.2 Analysis Methods

The alternatives being evaluated in this DEIS differ in the way Glen Canyon Dam would be operated under each over the next 20 years. The resource goal for cultural resources is to maintain the integrity of *National Register*-eligible or listed cultural resources in place, where possible, with preservation methods employed on a site-specific basis. There is the potential for the alternatives to affect cultural resources along the river corridor downstream of Glen Canyon Dam via differing flow patterns or non-flow actions. This section focuses on two specific types of historic properties: archeological sites and historic districts; Section 4.9 focuses on other types of historic properties, including cultural landscapes and TCPs that are specifically important to Tribes. Section 4.9 also discusses other resources that are important to Tribes as contributing elements to their TCPs, but which may not qualify for listing on the *National Register* independently. The variables considered include direct flow effects (i.e., erosion of river margin

1 sediments, deposition of sediments along the river margin, and inundation of sites), indirect
2 effects (i.e., changes in the availability of sediment for redistribution by wind, erosion resulting
3 from reduced sediment availability), and cumulative effects. The analysis relied on both
4 quantitative and qualitative information to determine the potential effects of each of the
5 alternatives. Three indicator metrics (1 in GCNRA and 2 in GCNP) were identified to describe
6 the relative differences among the alternatives in order to evaluate the range of potential impacts
7 on cultural resources.

8
9 For this analysis, cultural resources, as described in Section 3.8, that are potentially
10 affected by Glen Canyon Dam operations are archeological resources (including historic and
11 prehistoric structures), TCPs, and ethnographic resources. While museum objects are defined as
12 cultural resources, there are no effects or differences in effects on these classes of resources from
13 the alternatives and will therefore not be discussed in the text. Impacts on cultural landscapes are
14 not discussed separately, but any impacts on other resources (e.g., vegetation, wildlife, and
15 sediment) are considered to have an effect on the landscape.

16
17 The physical attributes of cultural resources are nonrenewable, with few exceptions, and
18 the primary concern is to minimize the loss or degradation of culturally significant material.
19 Cultural resources analyzed within the Colorado River corridor range from artifact scatters,
20 dwellings (both prehistoric and historic), resource collection areas, food preparation (roasting
21 and food processing) activity areas, horticultural areas, and petroglyph and pictograph panels,
22 collectively representing more than 12,000 years of human history.

23
24 Direct flow effects from releases from Glen Canyon Dam are most noticeable in the river
25 reach immediately below the dam. This is primarily because this reach has little sediment input
26 to help buffer the river terraces, and to a lesser degree because the affected resources are found in
27 closer proximity to the Colorado River in this reach. In GCNP, most affected resources are
28 located on terraces that are primarily affected indirectly by dam operations. Over time, flows and
29 climatic conditions could affect the terraces on which archeological sites are located.

30
31 An indicator of flow effects that was considered in the analysis is the erosion of elevated
32 terraces in the Glen Canyon reach, which was evaluated using a flow effects metric for Ninemile
33 Terrace. In general, repeated inundation of the toe of a terrace could produce slumping of the
34 terrace face, which could destroy or destabilize the cultural resources within or on the terrace
35 deposits. The toe of Ninemile Terrace is estimated to be inundated when flows reach 23,200 cfs.
36 The flow effects metric considered the frequency of when flows under the various alternatives
37 reach levels that could create conditions that could result in terrace edge slumping and,
38 ultimately, how they could affect the archeological sites within or on the terraces. The results of
39 the metric were expressed as the number of days per year that the maximum daily flow would be
40 >23,200 cfs under each alternative. See Appendix H for additional information on the flow
41 effects metric.

42
43 Another historic property in GCNRA that was considered when assessing direct flow
44 effects under the alternatives is the Spencer Steamboat site, which lies within the Colorado River
45 channel. Although the flow effects metric did not reveal any appreciable difference among

1 alternatives in effect on the Spencer Steamboat, impacts are still possible under the 20-year
2 duration of the LTEMP from repeated exposure to high flows and repeating cycles of inundation
3 and exposure. The wet-dry cycling resulting from fluctuations in lower flow levels contributes to
4 the deterioration of structural elements. Flow levels that expose the steamboat also increase the
5 potential for impacts from visitation and the accumulation of debris resulting in damage to
6 fragile remains.

7
8 Visitor effects are frequently noted at many of the archeological sites along the river;
9 these include the moving or theft of artifacts on archeological sites and the defacing of
10 inscriptions, pictographs, and petroglyphs. A metric, visitor time off river, was developed to
11 characterize how the various alternatives could influence the frequency at which archeological
12 sites could be visited by people on river trips. The metric considered flow rates under the various
13 alternatives during the summer months, when the number of visitors on the river is at its highest.
14 The metric reflects the degree to which, due to the flows under an alternative, visitors would be
15 able to spend more time exploring off of the river, which could result in more cultural resources
16 being visited and possibly affected. See Appendix H for additional information on the time off
17 river metric.

18
19 Erosion poses a threat to maintaining the condition of many of the archeological sites in
20 both GCNRA and in GCNP. Any actions that help retain sediment are considered to have a
21 potentially positive effect on maintaining the condition of archeological sites in the canyons
22 because they aid in maintaining the river corridor landscape and site stability. Most of the
23 archeological sites along the Colorado River are located on terraces that represent the river
24 terraces of the predam river system. Prior to construction of the dam, the terraces would have
25 been directly affected by flooding on a 7–10 year return interval (Topping et al. 2003), and
26 many contain flood deposits indicating they were flooded during or after occupation
27 (see Schwartz et al. 1979; Bright Angel Site). The persistent removal of sediment from the
28 system is a long-term effect on cultural resources resulting from the presence of the dam and will
29 continue under all alternatives. While sites may experience sediment transport (both aggradation
30 and degradation), the amount of possible sediment transport is unknown. Sediment availability in
31 the system for transport by the wind is linked to alternatives that include more HFEs (which
32 deposit sediment in locations that may allow for transport by the wind) and sediment retentive
33 flows. As discussed in Section 3.8, research has shown (Draut and Rubin 2008) that sediment
34 deposited by HFEs can be transported by the wind to terraces that contain historic properties
35 where that sediment could help stabilize these properties. The actual extent to which current
36 sediment levels can stabilize the archeological sites on the terraces remains unknown. Sediment
37 can also be removed from archaeological sites by wind and rain, factors that could lead to loss of
38 integrity of an historic property.

39
40 A Wind Transport of Sediment Index addresses the potential for sediment to be
41 transported by the wind to the terraces along the river which contain hundreds of archeological
42 sites. The metric reflects when conditions exist for movement of sediment by wind, and therefore
43 the potential exists for cultural resources to receive sand and potentially be protected, under each
44 alternative. Optimal conditions for wind transport of sediment occur when (1) fine sediment is
45 deposited by flows above the stage of normal operations, and (2) low flows occur during the

1 windy season (March–June), which exposes dry sand for potential redistribution by the wind.
2 The metric used the Sand Load Index and a flow factor which captures the frequency of low
3 flows in the spring for each alternative. See Appendix H for additional information on the wind
4 transport index. There would be a great deal of variability from site to site throughout the system
5 with regard to the amount of sand deposited upwind by HFEs and the exposure of sediment at
6 varying flows.

7
8 Another element incorporated into the alternatives is non-flow vegetation management
9 efforts. All of the alternatives except for Alternative A incorporate non-flow vegetation
10 management efforts (Section 4.6). Vegetation removal could increase erosion near an
11 archeological site, or create more open sand, which could facilitate wind transport and deposition
12 of sediment onto terraces. The effect of non-flow vegetation management is not considered in the
13 alternative-specific discussions because any vegetation management efforts would be
14 coordinated with the cultural resources managers and would therefore not be anticipated to affect
15 known cultural resources.

16
17 Each of the alternatives has the potential to affect cultural resources. These effects can be
18 beneficial, meaning the alternative results in increased stability or preservation of cultural
19 resources in the APE, or they can be adverse when an alternative results in destabilization of
20 these resources. It is also possible that the alternatives would have no additional effect beyond
21 those already occurring. The effects of alternatives could differ due to varying frequency, timing,
22 and magnitude of daily flows, HFEs, and of the intervening flows between HFEs.

23 24 25 **4.8.3 Summary of Impacts**

26
27 Although the alternatives vary significantly in how water is released from Glen Canyon
28 Dam within a year, the range of effects alternatives would have on cultural resources is expected
29 to be minimal (Table 4.8-1), in part because annual water release volumes among alternatives
30 would be nearly identical and cultural resources are dependent upon landform stability, a
31 consideration that is primarily controlled by the amount of sediment in the system. The majority
32 of cultural resources within the APE would not be inundated under any alternative, but some
33 sites could experience indirect effects. Appendix H provides the results for each of the
34 quantitative metrics considered in this analysis.

35
36 It has been noted that the potential for degradation of terrace stability at Ninemile Terrace
37 is currently estimated to begin at 23,200 cfs when flows can begin to erode the toe of the terrace
38 (Baker 2013). Erosion of the toe of a terrace can undermine the stability of the terrace and lead to
39 slumping, as was noted after the 1996 HFE (Baker 2013), a 168-hr 45,000-cfs flow. This single
40 event demonstrated that terrace bank erosion may occur as flow elevations increase, during the
41 period of peak high flow, and following the decrease of high flows to normal operational levels.
42 Under most of the LTEMP alternatives, the greatest flows would be 45,000-cfs flows lasting for
43 96 hr (Section 4.3); these would be comparable to or less than flows that have occurred
44 historically that resulted in slumping. The only alternatives in which this duration could be
45 exceeded are Alternatives D and G. Alternatives D and G allow for longer duration HFEs (up to

1 **TABLE 4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen and Grand Canyons**

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions which may contribute to slumping of terraces in Glen Canyon. HFEs will deposit additional sediment which will be available for wind transport; however, it is expected that the additional sediment will not significantly improve the stability of archaeological sites in Grand Canyon. No change from current conditions related to the stability of Spencer Steamboat and visitor time off river.	Similar to Alternative A.	Compared to Alternative A, operations could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect to the stability of Spencer Steamboat and time off river.	Compared to Alternative A, extended-duration HFEs could result in additional destabilization of terraces in Glen Canyon but could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect on the stability of Spencer Steamboat and time off river.	Compared to Alternative A, operations could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect on the stability of Spencer Steamboat and time off river.	Compared to Alternative A, operations could result in additional destabilization of terraces in Glen Canyon due to sustained high flows in the spring, but could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Small increase in the visitor time off river in June. Negligible effect on the stability of Spencer Steamboat.	Compared to Alternative A, extended-duration HFEs could result in additional destabilization of terraces in Glen Canyon, but could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect on the stability of Spencer Steamboat and time off river.
Erosion of terraces in Glen Canyon that support cultural resources	No change from current conditions which may contribute to slumping of terraces in Glen Canyon.	Similar to Alternative A.	Similar to Alternative A.	May influence erosion of landforms containing cultural resources in GCNRA due to extended-duration HFEs.	Similar to Alternative A.	May influence erosion of landforms containing cultural resources in GCNRA due to high flows in May and June.	May influence erosion of landforms containing cultural resources in GCNRA due to extended-duration HFEs.

4-221

TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Visitor effects on cultural resources	Negligible effect on time off river.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Small increase in visitor time off river in June when flows are high, which could result in cultural resources being visited more frequently; effect could be offset by the effects of lower flows in July–September.	Similar to Alternative A.
Wind transport of sediment to high-elevation cultural resources	Negligible influence on windblown sediment (index 0.16 out of 1); some benefit from HFES until 2020 when HFES are discontinued; potential adverse impact due to reduction in sediment availability after 2020.	Negligible influence on windblown sediment (index 0.17); some benefit from HFES over entire LTEMP period.	Some improvement in potential for windblown sediment (index 0.38) resulting from increase in frequency of HFES.	Similar to Alternative C (index 0.38).	Similar to Alternative C (index 0.31).	Similar to Alternative C (index 0.30.)	Similar to Alternative C (index 0.46).

4-222

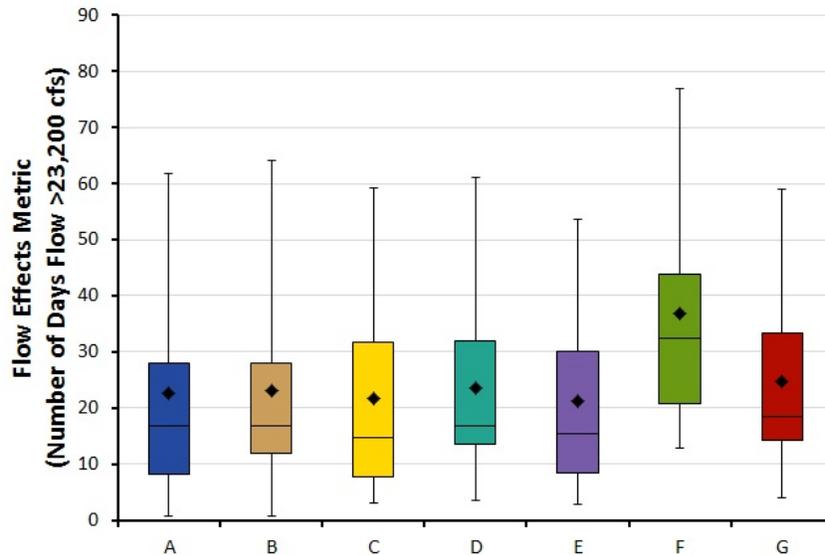
TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Spencer Steamboat	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known but potentially increase the risk of degradation.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known but potentially increase the risk of degradation.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative D.

1 250 and 336 hr, respectively) when there is adequate sediment. However, flows will reach the
 2 lower threshold of 23,200 cfs under all alternatives. Under most alternatives, HFEs would be
 3 limited in magnitude and duration, but the cumulative effect of more than one HFE in a year and
 4 in sequential years is not known, and could result in an even higher risk of slumping compared to
 5 the effects of individual HFEs.

6
 7 The results from the Glen Canyon flow effects metric are shown in Figure 4.8-1.
 8 Alternative A most closely represents the current operational conditions. Under the metric,
 9 Alternative F would have the highest number of days per year; flows would be >23,200 cfs with
 10 an average of 14 days per year more than under Alternative A. Alternative F, therefore, has the
 11 highest potential for impacts on terraces that contain cultural resources in Glen Canyon. The
 12 higher number of days under Alternative F results from the relatively high spring flows between
 13 May and June (Section 2.3.6). The remaining alternatives have an average number of days per
 14 year where flows would be >23,200 cfs within 4 days of those under Alternative A.

15
 16 Although there are differences among alternatives in the number of HFEs, these
 17 differences have little effect on the number of days per year flows would be >23,200 cfs. This
 18 occurs because HFEs are relatively brief, and the large volume released under the HFE must be
 19 compensated by releasing less water at other times of year. Since all alternatives must release the
 20 same annual volume of water, alternatives with HFEs may have lower releases at other times of
 21
 22



23

24 **FIGURE 4.8-1 Number of Days per Year Flows Would Be**
 25 **>23,200 cfs under LTEMP Alternatives (letters). (Flows of this**
 26 **magnitude have the potential to affect cultural resources in Glen**
 27 **Canyon. Note that diamond = mean; horizontal line = median;**
 28 **lower extent of box = 25th percentile; upper extent of box =**
 29 **75th percentile; lower whisker = minimum; upper whisker =**
 30 **maximum.)**

1 years than those without. The effect on the metric would be greater in years of high volume
2 (≥ 10 maf) when equalization flows would be implemented according to the Interim Guidelines
3 (Reclamation 2007a).
4

5 A persistent source of impacts on cultural resources is visitors (Bulleys et al. 2008, 2012;
6 Jackson-Kelly et al. 2013). The effects being identified include the moving of artifacts on
7 archaeological sites and the defacing of inscriptions, pictographs, and petroglyphs. The LTEMP
8 does not incorporate any specific recommendations or policies concerning visitors under any
9 alternatives. The Colorado River Management Plan (CRMP) is the primary document addressing
10 visitor policies related to cultural resources in GCNP (NPS 2005a). Because LTEMP alternatives
11 do not alter any policies concerning visitors, they do not differ with respect to any direct effect
12 caused by visitors on cultural resources. Visitor effects are discussed under cumulative impacts.
13

14 An indirect effect related to visitor disturbances to cultural resources concerns the amount
15 of time boaters have off river to explore and potentially interact with archaeological sites. More
16 time would be available when flows are higher during the tourist season (June–September), and
17 this factor could vary among alternatives. Analysis determined that the time off river did not vary
18 among most alternatives. However, Alternative F has higher flows during May and June, so it
19 could provide for more time off river during those months; these higher flows are offset by lower
20 flows in July, August, and September when time off river would be less than for other
21 alternatives.
22

23 The Spencer Steamboat, located in GCNRA, could be directly affected by flows. The
24 steamboat lies in the river, is part of the Lees Ferry/Lonely Dell Ranch National Historic District,
25 and has been subject to all past dam releases, including HFEs (2012, 2013, and 2014), extended-
26 duration HFEs (1996), low flows (2002), fall steady flows (2011–2013), and higher fluctuation
27 flows (pre-1992). Although the site appears to be receiving an ongoing accumulation of
28 sediment, which is beneficial for site preservation, ongoing monitoring has demonstrated that the
29 wet-dry cycling resulting from fluctuations at low flow levels has caused the most obvious and
30 persistent impacts on the site, as predicted by Carrel (1987). The recent installation of submerged
31 monitoring stations (Pershern et al. 2014) will allow the opportunity to systematically evaluate
32 the nature and origin of sediment accumulating at the site, and determine how that mechanism of
33 transport may be influenced or affected by dam operations. Because the proposed flows do not
34 exceed or vary greatly from past flows, similar effects are anticipated under any of the
35 alternatives. The cumulative effects of multiple HFEs and extended-duration HFEs on the
36 Spencer Steamboat are not known and could increase the risk of degradation.
37

38 The results from the Wind Transport of Sediment Index under the various alternatives are
39 shown in Figure 4.8-2. Alternative G scores the highest of all the alternatives, with an average
40 index value nearly three times greater than Alternative A. Alternative G has the highest number
41 of HFEs and the lowest maximum daily flows during the windy months. Alternative G has
42 parameters which are ideal for wind-transport of fluvial sediment to terraces that contain cultural
43 resources. The second highest scoring alternative is Alternative D.
44

45 On the whole, the Wind Transport of Sediment Index is highly correlated to the number
46 of HFEs and the corresponding Sand Load Index. The relationship between the Sand Load Index

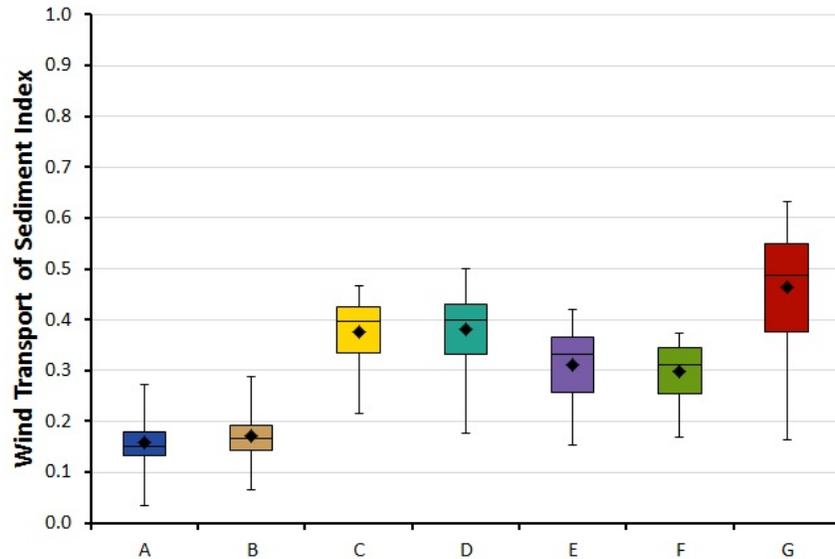


FIGURE 4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives (letters) (Values of 1 are considered optimal. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

and HFEs is discussed in Appendix E. The Wind Transport of Sediment Index is highly correlated to the Sand Load Index because the average maximum discharge between March and June for each of the alternatives is within 5,000 cfs. With minimal difference in flow, the amount of sediment for distribution becomes the determining factor for the index. The exception to this is Alternative F. Although Alternative F was determined to have the second highest potential sand deposition (second highest Sand Load Index, only less than Alternative G), it ultimately has an average index value lower than Alternatives C, D, E, and G because larger discharges of water create less ideal conditions for wind transport.

4.8.4 Alternative-Specific Impacts

4.8.4.1 Alternative A (No Action Alternative)

Dam operations under Alternative A are expected to continue to contribute to conditions that could affect terraces that contain cultural resources in Glen Canyon. Observations in Glen Canyon noted that effects on the toe of the resource-bearing terrace at Ninemile Terrace begin with flows above 23,200 cfs (Baker 2013). Under Alternative A, flows could exceed 23,200 cfs and create conditions that could affect the stability of resource-bearing terraces. However, based on no significant deterioration of the Ninemile site since the 1996 flows, the effects of HFEs and interim operations on terraces in Glen Canyon under Alternative A would not be expected to

1 change from current conditions. However, the cumulative effects of daily flows and the lack of
2 sediment availability remain factors which could affect the stability of the terraces and continue
3 to create the potential for effects as identified under the current MLFF operation. There would be
4 no change from current conditions with respect to the stability of Spencer Steamboat, but the
5 cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase
6 the risk of degradation.

7
8 In Grand Canyon, sandbar building that would result from HFEs under Alternative A
9 could provide windblown sediment to high terraces; however, based on observations of existing
10 conditions, this effect is expected to be small and would be reduced after HFEs were
11 discontinued under this alternative in 2020. Alternative A is not expected to significantly
12 improve the stability of archaeological sites.

13
14 In summary, operations under Alternative A could result in conditions which may
15 contribute to slumping of terraces in Glen Canyon, although these effects are expected to be
16 similar to those under current conditions. Operations under Alternative A are not expected to
17 significantly improve the stability of archaeological sites in Grand Canyon. There would be no
18 change from current conditions with respect to the stability of Spencer Steamboat or visitor time
19 off river and subsequent effects on cultural resources.

20 21 22 **4.8.4.2 Alternative B**

23
24 Dam operations under Alternative B are not expected to have additional effects on
25 terraces that contain cultural resources in Glen Canyon. Daily fluctuations under Alternative B
26 would be higher than under Alternative A. In addition, experimental hydropower improvement
27 flows under this alternative could result in daily flows of 25,000 cfs between December and
28 February, as well as between June and August. However, these wider daily fluctuations are not
29 expected to result in increased erosion rates because the alternative results in only a slight
30 increase in the number of days when the base of the terraces in GCNRA would be inundated
31 (i.e., flows >23,200 cfs) compared to Alternative A, which would result in a minor increase in
32 the potential for slumping. There would be no change from current conditions with respect to the
33 stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer
34 Steamboat are not known and could increase the risk of degradation.

35
36 It is anticipated that there will be some increase in the amount of sediment available for
37 wind transport under Alternative B; both Alternatives A and B are expected to have
38 approximately the same number of HFEs. Alternative B is expected to have a smaller beneficial
39 effect from windblown sediment in Grand Canyon relative to other alternatives that have more
40 frequent HFEs. With hydropower improvement flows, there is expected to be a minor decrease
41 with respect to wind transport compared to Alternative A.

42
43 In summary, operations under Alternative B could result in conditions which may
44 contribute to slumping of terraces in Glen Canyon, although these effects are expected to be
45 similar to those under Alternative A. Operations under Alternative B are not expected to
46 significantly improve the stability of archaeological sites in Grand Canyon. There would be no

1 change from current conditions with respect to the stability of Spencer Steamboat or visitor time
2 off river and subsequent effects on cultural resources.

3 4 5 **4.8.4.3 Alternative C**

6
7 Dam operations under Alternative C are not expected to have any additional effects on
8 terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative C
9 would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was
10 only observed after the 1996 HFE of 168 hr, the cumulative effect of multiple HFEs on the
11 stability of terraces is not known. Compared to Alternative A, operations under Alternative C
12 would not result in a substantial increase in the number of days when the base of the terraces in
13 GCNRA would be inundated (i.e., flows $\geq 23,200$ cfs; thus, there is no measurable difference in
14 the potential for increased slumping. There would be no change from current conditions with
15 respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and
16 extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of
17 degradation.

18
19 The amount of sediment available for wind transport in Grand Canyon under
20 Alternative C is greater than under Alternative A because there would be more frequent HFEs
21 through the entire 20-year LTEMP period, increased sediment retention resulting from lower
22 daily fluctuations, proactive spring HFEs in wet years, and reduced fluctuations before and
23 after HFEs.

24
25 In summary, operations under Alternative C could result in conditions which may
26 contribute to slumping of terraces in Glen Canyon, although these effects are expected to be
27 similar to those under Alternative A. There could be some improvement in the potential for
28 windblown sediment to protect archaeological sites on terraces in Grand Canyon. There would
29 be no change from current conditions with respect to the stability of Spencer Steamboat or visitor
30 time off river and subsequent effects on cultural resources.

31 32 33 **4.8.4.4 Alternative D (Preferred Alternative)**

34
35 Dam operations under Alternative D could result in some additional destabilization of
36 terraces that contain cultural resources in Glen Canyon. This could result from the extended-
37 duration HFEs (up to 250 hr) that would be implemented as an experimental treatment in years
38 when large inputs of sediment from the Paria River occur. No more than four extended-duration
39 HFEs would be implemented during the LTEMP period under Alternative D. Some slumping
40 was observed in Glen Canyon as a result of the 1996 HFE, which had a magnitude of 45,000 cfs
41 and duration of 168 hr. In addition, the cumulative effect of multiple HFEs on the stability of
42 terraces is not known. Compared to Alternative A, operations under Alternative D would result in
43 a slight increase in the number of days when the bases of the terraces in GCNRA would be
44 inundated (i.e., flows $\geq 23,300$ cfs), which would result in a slightly increased potential for
45 slumping. There would be no change from current conditions with respect to the stability of

1 Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on
2 the Spencer Steamboat are not known and could increase the risk of degradation.

3
4 In Grand Canyon, the amount of sediment available for wind transport under
5 Alternative D is greater than under Alternative A because there would be more frequent HFEs
6 through the entire 20-year LTEMP period, increased sediment retention resulting from slightly
7 lower daily fluctuations, proactive spring HFEs in wet years, and reduced fluctuations before and
8 after fall HFEs.

9
10 In summary, operations under Alternative D could result in additional destabilization of
11 terraces in Glen Canyon. There could be some improvement in the potential for windblown
12 sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change
13 from current conditions with respect to the stability of Spencer Steamboat or visitor time off
14 river and subsequent effects on cultural resources.

15 16 17 **4.8.4.5 Alternative E**

18
19 Dam operations under Alternative E are not expected to have any additional effects on
20 terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative E
21 would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was
22 only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple
23 HFEs on the stability of terraces is not known. Compared to Alternative A, operations under
24 Alternative E do not result in a substantial increase in the number of days when the base of the
25 terraces in GCNRA would be inundated (i.e., flows $\geq 23,200$ cfs), which would result in no
26 measurable difference in the potential for increased slumping. There would be no change from
27 current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects
28 of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of
29 degradation.

30
31 In Grand Canyon, the amount of sediment available for wind transport under
32 Alternative E is greater than under Alternative A because there would be more frequent HFEs
33 through the entire 20-year LTEMP period (although fewer than under Alternatives C, D, F,
34 and G).

35
36 In summary, operations under Alternative E could result in conditions which may
37 contribute to slumping of terraces in Glen Canyon, although these effects are expected to be
38 negligible. There could be some improvement in the potential for windblown sediment to protect
39 archaeological sites on terraces in Grand Canyon. There would be no change from current
40 conditions with respect to the stability of Spencer Steamboat or visitor time off river and
41 subsequent effects on cultural resources.

1 **4.8.4.6 Alternative F**
2

3 Alternative F is expected to have additional effects on terraces that contain cultural
4 resources in Glen Canyon because there would be an increase in the number of days when the
5 bases of terraces in GCNRA would be inundated. Flows in May and June would be sustained at
6 higher levels under this alternative, resulting in an increased number of days in wetter years
7 when the bases of the terraces would be inundated, compared to Alternative A. Although HFEs
8 would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the bases of terraces was
9 only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple
10 HFEs on the stability of terraces is not known. Compared to Alternative A, operations under
11 Alternative F would result in an increase in the number of days when the bases of the terraces in
12 GCNRA would be inundated (i.e., flows $\geq 23,200$ cfs), which would result in an increased
13 potential for slumping. There would be no change from current conditions with respect to the
14 stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer
15 Steamboat are not known and could increase the risk of degradation.
16

17 Dam operations under Alternative F would allow faster travel times for boaters in May
18 and June; therefore, boaters would have additional time off river to visit cultural resources during
19 those months. This increase would be offset by the effects of lower flows in July–September.
20 Alternative F is the only LTEMP alternative that, based on the analysis, could have any influence
21 on visitor effects.
22

23 In Grand Canyon, the amount of sediment available for wind transport under
24 Alternative F is greater than under Alternative A because there would be more frequent HFEs
25 through the entire 20-year LTEMP period and increased sediment retention from low steady
26 flows throughout much of the year. However, the highest flows under Alternative F are in May,
27 which reduces the potential for wind transport of sediment to terraces during this windy period.
28

29 In summary, operations under Alternative F could result in additional destabilization of
30 terraces in Glen Canyon. There could be some improvement in the potential for windblown
31 sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change
32 from current conditions with respect to the stability of Spencer Steamboat; there could be a small
33 increase in the visitor time off river in May and June, which could result in increased visitation
34 and potential damage to cultural resources.
35
36

37 **4.8.4.7 Alternative G**
38

39 Dam operations under Alternative G could result in some destabilization of terraces that
40 contain cultural resources in Glen Canyon. This could result from the extended-duration HFEs
41 (up to 336 hr) that would be implemented in years when large inputs of sediment from the Paria
42 River occur. Some slumping was observed in Glen Canyon as a result of the 1996 HFE, which
43 had a magnitude of 45,000 cfs and duration of 168 hr. In addition, the cumulative effect of
44 multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations
45 under Alternative G would result in an increase in the number of days when the bases of the
46 terraces in GCNRA would be inundated (i.e., flows $\geq 23,300$ cfs), which would result in an

1 increased potential for slumping. There would be no change from current conditions with respect
2 to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-
3 duration HFEs on the Spencer Steamboat are not known and could increase the risk of
4 degradation.

5
6 In Grand Canyon, the amount of sediment available for wind transport under
7 Alternative G would be greater than under Alternative A because there would be more frequent
8 HFEs through the entire 20-year LTEMP period, increased sediment retention from steady flows
9 throughout the year, and proactive spring HFEs in wet years. Alternative G has the lowest spring
10 operational flows when windy conditions are most typical. These factors create the best
11 conditions under any of the alternatives for wind transport of sediment to the terraces.

12
13 In summary, operations under Alternative G could result in additional destabilization of
14 terraces in Glen Canyon. There could be some improvement in the potential for windblown
15 sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change
16 from current conditions with respect to the stability of Spencer Steamboat or visitor time off
17 river and subsequent effects on cultural resources.

18 19 20 **4.9 TRIBAL RESOURCES**

21
22 Assessing the comparative impacts of the
23 LTEMP alternatives on Tribal resources presents
24 a challenge both because of the Tribes' holistic
25 view of the Canyons, in which all things are
26 interconnected, and because there is no single
27 "Tribal view" held by all members of all Tribes.
28 The holistic view encompasses most of the
29 subject areas considered in this DEIS and Tribal
30 perspectives on these resources are found
31 throughout the document.

32
33 The values placed by the Tribes on the
34 river and its Canyons are significant and real but
35 may be intangible; thus, they are not easily
36 quantifiable. In addition, many of the values and
37 resources most important to the Tribes are not
38 directly affected by the proposed action as
39 defined by operational patterns of water releases
40 from Glen Canyon Dam.

41 42 43 **4.9.1 Tribal Resource Goals**

44
45 As discussed in Section 3.9, the Tribes
46 that have the closest ties to the Canyons and are

Issue: How do alternatives affect Tribal resources in Glen, Marble, and Grand Canyons?

Impact Indicators:

- Health of the ecosystem including vegetation, wildlife, fish, and wetlands
- Water rights
- Condition of traditional cultural places

Issue: How do alternatives affect the sacred integrity of and Tribal connections to the Canyons?

Impact Indicators:

- Stewardship and educational opportunities
- Independent access to Canyons
- Number of nonnative fish removed each year
- Economic opportunity
- Incorporating traditional knowledge into the LTEMP EIS

1 most actively involved in the LTEMP DEIS process are the Havasupai, Hualapai, Hopi, Kaibab
2 Band of Paiutes, Navajo Nation, Pueblo of Zuni, and Fort Mojave Indian Tribe. Eight important
3 themes or values relative to the Colorado River and its Canyons emerged from meetings,
4 workshops, and webinars held with individual Tribal representatives and from reviewing
5 ethnographies and Canyon monitoring reports produced by or for the Tribes. These have been
6 identified as Tribal resource goals for the LTEMP DEIS and grouped according to whether they
7 can be represented quantitatively and whether they would be differentially affected by alternative
8 management practices at or related to the operation of Glen Canyon Dam. An initial evaluation
9 was made based on Tribal sources, and the Tribes were afforded the opportunity to review and
10 provide input.

11
12 For this discussion, Tribal resources are divided into two categories: (1) traditional
13 cultural places—those elements with fixed and defined locations, and (2) traditional cultural
14 resources—resources that are either widely scattered or mobile, such as riparian vegetation,
15 birds, mammals, and fishes. For many Tribes, resources in these two categories may be
16 considered TCPs or contributing elements to a TCP and may be differently affected by flow and
17 non-flow elements of the seven LTEMP alternatives.

18 19 20 **4.9.1.1 Increase the Health of the Ecosystem in Glen, Marble, and Grand Canyons**

21
22 Tribes such as the Hopi express their perception of the state of the Canyons in terms of
23 the Canyons' health (Yeatts and Huisinga 2003, 2006, 2009, 2010, 2011, 2012, 2013). For the
24 Hopi, natural elements and resources are significant for creating a culturally significant,
25 harmonious landscape. Without them, the landscape would not be whole. These resources,
26 because they are either widely scattered or mobile, rather than existing in a fixed location, may
27 be considered traditional cultural resources.

28
29 Although the affected Tribes are concerned with the state of the Canyons as a whole, they
30 tend to be especially focused on the riparian corridor because of its association with emergence
31 narratives, and in some cases the Tribes give particular value to native plants. The determination
32 of Canyon health from a Tribal point of view is to some extent subjective. For example, a recent
33 survey of Hopi Canyon monitors showed that most respondents found the Canyons to be in good
34 health, or at least better taken care of than in the past, in part because of Hopi participation in the
35 adaptive management process by monitoring important sites such as the salt mine, and because
36 of the offerings made in the Canyons by Tribal members (Yeatts and Huisinga 2013). Some
37 aspects of Canyon health are quantifiable and parallel or reflect values that have been expressed
38 by the Tribes or their representatives. These include riparian plant diversity, wetland abundance,
39 and characteristics of native fish populations considered here. The interest of the Tribes extends
40 beyond these measures to impacts on other aspects of Canyon health explored elsewhere in this
41 chapter, including natural processes (Section 4.4), aquatic ecology (Section 4.5), vegetation
42 (Section 4.6), wildlife (Section 4.7), hydropower (Section 4.13), and environmental justice
43 (Section 4.14).

44
45 The Western concept of ecosystem has much in common with the Tribes' view of their
46 place in an interconnected natural world. Plant communities form a fundamental aspect of any

ecosystem, and vegetation health is an indicator of ecosystem health. Metrics for vegetation community diversity and wetland abundance in the riparian zone most directly affected by flow management at the Glen Canyon Dam have been developed based on the results of an existing state and transition model developed by GCMRC for Colorado River riparian vegetation downstream of Glen Canyon Dam; this is described by Ralston et al. (2014) and in Appendix G and discussed in Section 4.6.1. The metrics are on a scale relative to starting conditions where a higher value means greater vegetation community diversity or wetland abundance relative to starting conditions.

A healthy ecosystem from a Tribal perspective is characterized by a high degree of species diversity, represented here by diversity in vegetation community types. The model projects transitions over the 20-year LTEMP period for each alternative analyzed. During discussions with the Tribes, they often expressed their view that all forms of life have value, whether native or nonnative. To take this perspective into account, evaluation of diversity included nonnative (primarily tamarisk) as well as native vegetation, including the invasive arrowweed. The analysis indicated that all alternatives on average would result in a decrease in total vegetation diversity over the 20-year LTEMP period.

The loss in diversity would be greatest under Alternatives C, F, and G. Under these alternatives, the acreage occupied by the invasive tamarisk increases (Table 4.9-1). Alternatives under which tamarisk⁹ would increase are characterized by spring high flows (HFEs or ≥ 30 days

TABLE 4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover

Alternative	Mean Diversity Score ^a	Change in Tamarisk Cover (ac)
A	0.95	-58.4
B	0.97	-71.3
C	0.75	104.0
D	0.94	-22.4
E	0.93	-45.7
F	0.70	230.7
G	0.83	46.4

^a Higher values of diversity indicate better condition relative to other alternatives. A value less than 1 indicates an expected reduction in diversity relative to current conditions over the 20-year LTEMP period. A value greater than 1 indicates an expected increase in diversity.

⁹ The model takes into account the effects of scouring, drowning, desiccation, and sediment deposition, but does not account for the effects of the tamarisk leaf beetle or tamarisk weevil. These two insect species are expected to result in a reduction in the amount of live tamarisk in the river corridor.

1 with flows >20,000 cfs), which serve to distribute seed, followed by low flows in the growing
2 season (May–September) which would allow seedlings to establish themselves. Alternative B
3 results in the least loss of diversity, followed by Alternatives A, D, and E. Under these
4 alternatives, the area covered by tamarisk decreases.

5
6 Another indicator of Canyon health is the abundance of wetlands in the riparian zone.
7 Although they make up only a small part of the riparian area of the river corridor (4.6 acres, or
8 0.5% of total area of all vegetation types), wetlands include plants of medicinal and cultural
9 significance to some Tribes (Jackson et al. 2001) that continue to be harvested with care (Yeatts
10 and Huisinga 2006). The Hopi generally see the marshes as healthy and well taken care of, but
11 there is some indication in the Tribal monitoring reports that cattail and reed marshes are
12 decreasing in size and number and that cattails are decreasing in number (Yeatts and
13 Huisinga 2013).

14
15 Based on the vegetation models discussed in Section 4.6, the change in abundance was
16 determined for each of the wetland community types (common reed wet marsh and
17 willow/baccharis/horsetail wetland). Wetlands would expand under hydrologic regimes that lack
18 extended periods of high flows (≥ 30 days with maximum daily flows >20,000 cfs) and extended
19 low flows (≥ 30 days with maximum daily flows <10,000 cfs), but are maintained with occasional
20 extended high flows (in many cases) or HFEs and an absence of extended low flows during the
21 growing season. Alternatives that include frequent extended low flows, such as the annual flows
22 for Alternative F, or extended high flows followed by extended low flows tend to result in
23 transitions of wetlands to other plant community types. All of the alternatives are expected to
24 result in a decrease in wetland cover, with particularly large decreases under Alternative F.

25
26 The state of aquatic life in the Canyons is discussed in Section 4.5. Section 4.5.2 presents
27 a summary of projected impacts on native and nonnative fishes and the aquatic food base. These
28 projections correlate well with recent results from the Hopi monitoring program, which found the
29 native fish populations in the Canyons, particularly the humpback chub, to be healthy (Yeatts
30 and Huisinga 2013).

31
32 Impacts on riparian and terrestrial wildlife are discussed in Section 4.7.2. Impacts on
33 indicators of wildlife and habitat health are expected to be limited, with no major differences
34 among the alternatives. Alterations in riparian vegetation and the aquatic food base are not
35 expected to be sufficient to adversely affect amphibians and reptiles over the long term;
36 however, alternatives could produce changes in near-shore aquatic and wetland habitats that are
37 important to amphibians and that serve as important food production areas for both amphibians
38 and reptiles (Section 4.7.2.2). The distribution of woody riparian vegetation is not expected to
39 vary enough under any alternative to disrupt the migration of riparian bird species or to have
40 noticeable differences in impacts on species that nest in riparian vegetation; however,
41 alternatives could produce changes in shoreline habitats that could affect waterfowl and wading
42 birds (Section 4.7.2.3). Impacts on mammals such as muskrat and beaver would be negligible
43 under all alternatives (Section 4.7.2.4). Larger mammals such as deer and bighorn sheep are
44 mobile and able to adjust their use of different habitats along the corridor. Impacts on bighorn
45 sheep under all alternatives are expected to be negligible (Section 4.7.2.4). A recent Hopi

1 monitoring report found birds, mammals, insects, and snakes in the Canyons all to be healthy
2 (Yeatts and Huisinga 2013).
3
4

5 **4.9.1.2 Protect and Preserve Sites of Cultural Importance**

6

7 Sites of cultural importance to the Tribes include archaeological sites, places associated
8 with traditional narratives of Tribal identity, rock writing, sacred places, offering sites, springs,
9 and traditional resource collection areas. As a group these may be referred to as traditional
10 cultural places. Expected effects of the alternatives on archaeological sites and historic properties
11 are discussed in Section 4.8. Other cultural resources associated with specific locations are likely
12 to experience the same types of impacts as those on archaeological sites. Those Tribes that
13 regularly monitor the condition of culturally important sites and resources in the Canyons most
14 often list intentional and unintentional damage to sites from visitors to the Canyons as the prime
15 threat to site integrity. Reported damage includes trailing, trampling, removal of vegetation,
16 disturbance of artifacts, vandalism, and disruption of the sacred context through inappropriate
17 behavior (Section 4.9.1.4). Bank erosion and inundation are mentioned less frequently in the
18 monitoring reports. The majority of visitors to the river corridor arrive by boat. Higher flows
19 have faster currents, so boaters travel more quickly between campsites, leaving more time to
20 explore off-river, which could lead to more visitation of cultural sites and a greater potential for
21 damage. Modeling of visitor time off the river indicates that there is almost no difference in
22 expected amount of time off river among the LTEMP alternatives, with the exception of
23 Alternative F. Under this alternative, boaters could spend slightly more time off the river in May
24 and June when flows are relatively high and steady. Overall, impacts on these sites of importance
25 are not expected to vary significantly as a result of visitation among the alternatives.
26

27 For the Tribes of the desert Southwest, all water is sacred and the places where it emerges
28 from the ground as seeps and springs are particularly sacred. Tribal members travel to sacred
29 springs in the Canyons to retrieve water for ritual use in their own communities
30 (Dongoske 2011b; Jackson-Kelly et al. 2013). Warm mineral springs, such as Pumpkin Springs,
31 are sacred and their waters are considered therapeutic (Austin et al. 2007). The Tribes are
32 concerned with the purity of these sacred waters and exercise stewardship over them, which can
33 include appropriate prayers and offerings at the springs and along sacred trails that lead to them.
34 The Hopi largely consider the springs to be healthy, as a result of their having access to the
35 springs and being able to perform appropriate stewardship activities (Yeatts and Huisinga 2009).
36 Occasionally, spring sources, such as Pumpkin Springs, may take on a murky, polluted
37 appearance and an HFE is welcome in order to flush out the muck and algae that have
38 accumulated. This may disrupt access for a short amount of time, but water levels return to
39 normal within a few weeks. During consultation, the Tribes that monitor Tribal resources in the
40 Canyons—Hopi, Hualapai, Navajo, Southern Paiute, and Zuni—all have expressed more concern
41 with damage to the springs and disrespect for the sanctity of the waters by non-Tribal visitors to
42 the Canyons than with inundation resulting from flow management. Hopi monitoring reports
43 suggest that the health of the springs is largely unaffected by the operation of Glen Canyon Dam.
44 Overall, adverse impacts on springs and seeps from operation of Glen Canyon Dam are expected
45 to be negligible, while the HFEs have some benefit.
46

1 Some adverse impacts can be mitigated through education and communication. All of the
2 Tribes with ties to the Canyons are affiliates of Native Voices on the Colorado River
3 (<https://nativevoicesonthecolorado.wordpress.com>) and many have their own outreach programs
4 developed to educate visitors to the Canyons regarding Tribal histories and affiliations with the
5 Canyons. This is discussed further in Section 4.9.1.4. Mitigation of potential effects on resources
6 of Tribal concern will be subject to ongoing consultation.
7
8

9 **4.9.1.3 Preserve and Enhance Respect for Canyon Life**

10
11 For those Tribes that hold the Canyons to be a sacred space, the plant and animal life are
12 integral elements without which its sacredness would not be complete. The Zuni, in particular,
13 have established a lasting familial relationship with all aquatic life in the Colorado River and the
14 other water sources in the Canyons (Dongoske 2011a). They consider the taking of life through
15 the mechanical removal of trout to be offensive, and to have dangerous consequences for the
16 Zuni. The confluence of the Colorado River and the Little Colorado River is considered a sacred
17 area because of its proximity to places identified in traditional Tribal narratives as the locations
18 of the Zuni and the Hopi emergence into this world and other important events. The killing of
19 fish in proximity to sacred places of emergence is considered desecration, and would have an
20 adverse effect on the Grand Canyon as a Zuni TCP. The Zuni expressed their view on this
21 subject in Section 3.9.6. In the past, the Zuni have expressed a willingness to consult with
22 Reclamation in good faith in “seeking and reaching agreement with the Zuni to avoid, reduce,
23 compensate for, or otherwise mitigate any adverse effects” (Zuni Tribal Council 2010). The Zuni
24 along with the Hualapai, Navajo, Kaibab Band of Paiute, and Hopi continue to consult with
25 Reclamation, the NPS, and other agencies regarding nonnative fish control. As noted in
26 Chapter 2, since 2011, the presence of whirling disease prohibits live removal of trout due to the
27 risk of spreading the disease to other waters. In the event that nonnative fish are removed,
28 Reclamation commits to live removal of nonnative fish whenever practicable and then only if the
29 best available science indicates that nonnative fish are posing a threat to endangered native fish
30 species. Reclamation has also committed to consult with the Tribes whenever live removal is not
31 feasible to determine acceptable mitigation for the adverse effect, such as beneficial use
32 (Reclamation 2012b). In the past, Reclamation and NPS have worked with the Tribes to
33 determine a beneficial use of the removed fish and will continue to do so during the 20-year
34 LTEMP period. Note that what is considered beneficial use may not be the same for all Tribes.
35

36 The purpose of trout management activities is to enhance the survival of the endangered
37 humpback chub by reducing the numbers of trout in the river. Reducing the trout population
38 would reduce competition with and predation on young-of-the-year chub near the confluence
39 with the Little Colorado River from trout moving downstream from reaches just below Glen
40 Canyon Dam (Section 4.5). Two forms of trout management have been proposed: TMFs and
41 mechanical removal. Each is being considered as a management action that may be triggered
42 when trout and/or chub populations are at specified levels. Trout management is included in all
43 alternatives except Alternative F, and mechanical removal is only possible under Alternative A
44 until 2020 (see Appendix J).
45

1 A TMF is a highly variable flow pattern of water releases at Glen Canyon Dam intended
2 to control the number of young-of-the-year trout in the Glen Canyon reach of the Colorado River
3 and, subsequently, the migration of trout to downstream areas such as the confluence of the Little
4 Colorado River (Chapter 2). A typical TMF would consist of several days at a relatively high
5 sustained flow (e.g., 20,000 cfs) that would prompt young fish to move into the shallows along
6 the channel margins and, depending on the time of year, would prompt spawning fish to
7 construct redds and lay eggs in nearshore shallow areas. The high flows would be followed by a
8 rapid drop to a low flow (e.g., 5,000 cfs), stranding young-of-the-year trout and, depending on
9 the time of year, possibly exposing the eggs, thus preventing them from hatching. With the
10 exception of Alternatives C and D, under which TMFs could be implemented early in the
11 LTEMP period even if not triggered by predicted high trout recruitment, TMFs may be triggered
12 during years in which trout recruitment in the Glen Canyon reach is anticipated to be high. Under
13 each of the alternatives in which TMFs are included, they would initially be conducted as
14 experiments; they would be implemented only if they prove to be successful in reducing the trout
15 population in the Glen Canyon reach. In general, TMFs would most likely be triggered when
16 spring HFEs, which can stimulate the food base and thus trout production, are followed by
17 relatively high steady summer flows. Where the number of HFEs is limited, as in Alternative B,
18 it is expected that TMFs would be triggered in fewer years. Modeling indicates TMFs would be
19 triggered most often under Alternative G. If TMFs prove successful, they would reduce the
20 number of times mechanical removal would be triggered.

21
22 Mechanical removal would employ electrofishing to stun and remove nonnative fish.
23 Usually, the removed fish would then be euthanized and put to some beneficial use. For example,
24 in one mechanical removal test, the trout were emulsified and used as fertilizer in the Hualapai
25 Tribal gardens (Reclamation 2011a). In their Comprehensive Fisheries Management Plan, the
26 NPS committed to put all removed nonnative fish (including trout) to beneficial use through
27 human consumption (NPS 2013e). GCMRC has modeled the number of years in which
28 mechanical removal would be triggered under various alternatives. In general, mechanical
29 removal would be triggered in far fewer years than TMFs. In general, when TMFs are projected
30 to be triggered in more years, mechanical removal of trout would be triggered in fewer years.
31 Modeling indicates that under Alternative G (the alternative under which the most TMFs would
32 be triggered), mechanical removal would never be triggered in more than 7 years out of 20.

33
34 With regard to fish management, the Tribes have expressed a preference for letting nature
35 take its course rather than intervening to mitigate the consequences of past actions. For example,
36 the Zuni have suggested that it could be that the emergence of whirling disease in trout is
37 nature's way of tempering out-of-balance fish dynamics. The Zuni and Hopi have also expressed
38 some doubt that the humpback chub population is endangered and have urged additional studies
39 of the relationship of the rainbow and brown trout to the humpback chub before undertaking the
40 large-scale removal of fish (Zuni Tribal Council 2010; Yeatts and Huisinga 2013). For them,
41 TMFs and mechanical removal are equally offensive and would be considered an adverse effect
42 on the Grand Canyon TCP. Likewise, the Hopi Tribe "recommends that efforts to understand
43 what are the limiting factors for the humpback chub (both habitat issues in mainstem and Little
44 Colorado River, and the life stage(s) where mortality rate is limiting) continue to be a focus of
45 aquatic research. In addition, management actions such as the translocation should be continued
46 as long as they are continuing to be successful" (Yeatts and Huisinga 2012). The Navajo also

1 prefer live removal; however, according to a separate Navajo Nonnative Fish Control
2 Agreement, if live removable is not feasible, Reclamation is to consult with the Navajo Nation to
3 determine a course of action, and that fish shall not be euthanized within the area 0.5 mi
4 upstream of the Little Colorado River to 0.5 mi downstream of the salt mine
5 (Reclamation 2012b).

6 7 8 **4.9.1.4 Preserve and Enhance the Sacred Integrity of Glen, Marble, and Grand** 9 **Canyons**

10
11 The preservation of the sacred integrity of the Canyons is vitally important to the Tribes.
12 Under the provisions of Executive Order 13007, both Reclamation and the NPS have obligations
13 to accommodate access to and ceremonial use of Indian sacred sites by Indian religious
14 practitioners; to avoid adversely affecting the physical integrity of sacred sites; and to maintain
15 the confidentiality of the location of sacred sites as requested by the Tribes. Inappropriate
16 behaviors and activities within the Canyons can negatively affect the sanctity of the Canyons.
17 Visitor impacts noted by Tribes include, but are not limited to, trampling of resources, lack of
18 respect for sacred sites, trailing, illegal collection of artifacts, artifact movement, vandalism, and
19 littering. Disruptive, boisterous behavior in the Canyons disturbs the spiritual ambiance that
20 surrounds sacred trails and sites. Many Tribes have reported experiencing discomfort when
21 performing ceremonies at certain sites within the river corridor because of the number and
22 behavior of visitors present. In some cases, Tribal members have been approached by curious
23 visitors during private ceremonies (Bulleets et al. 2008. 2012; Jackson-Kelly et al. 2013). During
24 consultation meetings, Tribal representatives expressed concerns regarding integrity of the
25 Canyons. For example, the Zuni expressed that from their perspective, any impact on the
26 Canyons is an impact on the Zuni people, because the spirits that are disturbed can bring adverse
27 consequences to the Zuni and their families; and the Navajo indicated that they have observed a
28 reduction in the strength of plants gathered from sites along the river to be used for medicinal
29 and ceremonial purposes, and have sought out other collection sites. In addition, visitor impacts
30 could diminish the feeling, association, settings, and materials of important places, aspects used
31 to evaluate the integrity of a traditional cultural place.

32
33 Non-Tribal visitors will continue to be present under all alternatives. As noted in
34 Section 4.8, Alternative F is modeled to result in slightly more visitor time off-river, resulting in
35 slightly more risk to sacred sites than the other alternatives. There is very little variation in the
36 modeled time off river among the other alternatives

37
38 Possible adverse effects on sacred sites that result from tourists in the Canyons could be
39 mitigated and in some cases prevented through communication and education. All of the Tribes
40 with historical and cultural ties to the Canyons are affiliates of Native Voices on the Colorado
41 River, an educational program that offers the Tribes a chance to share their historic and
42 contemporary perspectives of the Colorado River and the Canyons with river guides, river
43 outfitters, and the public. River guides and outfitters in turn share this information with their
44 clients on river trips (NVCR undated). In addition, some Tribes have developed their own
45 outreach programs. The Southern Paiute Consortium has developed outreach programs with
46 Colorado River guides, local schools and universities, and civic organizations. When they are

1 conducting monitoring trips or present in the corridor, the consortium also talks with Canyon
2 visitors. The goal of the program is to educate non-Tribal members about the Southern Paiute
3 history and broad cultural landscape of the Canyons (Bulleets et al. 2012). The Hualapai
4 encourage public outreach and education as a means of teaching people about negative impacts
5 on Hualapai resources (Jackson-Kelly et al. 2013). The Zuni have expressed interest in
6 developing an educational program that would allow Zuni cultural advisors to inform river
7 guides, boatmen, NPS, and Reclamation about the importance of Zuni history and traditional
8 issues as they are related to the Canyons (Dongoske 2011a). Reclamation and NPS are
9 committed to continue working with the Tribes to develop or continue development of education
10 and outreach programs. It is important that visitors to the Canyons understand the magnitude of
11 the consequences their presence has on Tribal resources and Tribal members.
12
13

14 **4.9.1.5 Maintain and Enhance Healthy Stewardship Opportunities and Maintain** 15 **and Enhance Tribal Connections to the Canyons**

16
17 During the development of the LTEMP DEIS, the Tribes expressed concern with
18 maintaining and improving their connection to the Canyons, including the stewardship
19 responsibilities given to them at creation or emergence. Stewardship is partly expressed through
20 their participation in the Glen Canyon AMWG and TWG, which encourage participation in an
21 open discussion of issues related to the operation of Glen Canyon Dam as well as the design of
22 monitoring and research conducted by the GCMRC.
23

24 The Tribes regard maintaining their connection to the Canyon through traditional
25 activities and fulfilling their stewardship responsibilities as vital. Tribal stewardship takes place
26 on many levels, including participation in the management of Canyon resources through
27 monitoring programs, ceremonial activities, and recounting oral histories. These stewardship
28 activities are important for all Tribal members, but they are particularly important for passing
29 down traditions and oral histories to Tribal youth. As discussed above, insensitive behavior by
30 Canyon visitors and researchers may disrupt the Tribes' ritual activities of stewardship and
31 passing cultural values connected to the Canyons to the next generation (Bulleets et al. 2008,
32 2012; Jackson-Kelly et al. 2013).
33

34 Adverse effects can be avoided or mitigated through continued communication; this
35 includes communicating about the timing and duration of HFEs. Many of the Tribes are
36 members of both the AMWG and TWG. Many Tribes also have their own monitoring programs
37 whereby resources and sites of importance are monitored, the health of the Canyon is examined,
38 sacred sites are visited, and respects are paid to the Canyon and its resources. Continued
39 communication and collaboration between the Tribes and federal agencies will enhance
40 stewardship opportunities for the Tribes, as will maintaining the Tribes' continued access to the
41 Canyons to conduct important religious practices necessary for continued stewardship.
42
43

1 **4.9.1.6 Economic Opportunity**
2

3 As discussed in Section 4.14.2.1, economic ventures currently operated by the Tribes and
4 Tribal members rely heavily on tourism both in and around the Canyons. These ventures include
5 commercial rafting on the river, tourist facilities in or near the Canyons, and vendors of Native
6 American crafts, such as jewelry, basketry, and ceramics, that rely heavily on trade with tourists.
7 Within the Canyons, the Grand Canyon West Corporation, owned by the Hualapai Tribe,
8 provides recreational facilities including river running below Diamond Creek. The Hualapai
9 River Runners provide day and overnight whitewater rafting trips, and flat-water day trips. The
10 Tribe (working with GCNP) also issues some permits for private whitewater boating below
11 Diamond Creek. The one-day whitewater boating trips create the largest river recreation impacts
12 within the Canyons (61 jobs and \$1.4 million in annual regional income), while day-use flat-
13 water trips also make a significant contribution (19 jobs and \$0.4 million in annual regional
14 income). The NPS CRMP (NPS 2006b), developed in consultation with the Hualapai Tribe,
15 places limits on the number and size of trips below Diamond Creek. There are a fixed number of
16 river trip launches allowed under the NPS plan and more demand than capacity. The number of
17 trips would not change as a result of any of the alternatives, so the impacts on the river runners
18 would be the same as Alternative A for all alternatives. The same annual economic impacts
19 would be expected under each of the alternatives.
20

21 The Hualapai, Havasupai, and Navajo all operate land-based tourist facilities in or
22 adjacent to the Canyons. The Havasupai operate a lodge, café, trading post, and campground on
23 their reservation, and offer Canyon tours. The Navajo have Tribal parks overlooking the Little
24 Colorado River and Grand Canyon, and along Lake Powell. Tourism is a major source of Tribal
25 income for the Hualapai and Havasupai. No difference in tourist use of land-based facilities or
26 Native American craft vendors is expected among the LTEMP alternatives. However, Tribes
27 have expressed the desire for communication before and during HFEs to enable them to
28 communicate information to tourists as necessary. The Navajo also operate the Antelope Point
29 Marina on Lake Powell. Direct and indirect economic impacts of visitation to Lake Powell
30 facilities are discussed in Section 4.14.2.1. There is very little difference among the alternatives
31 regarding impacts on marinas on Lake Powell. Models indicate that all alternatives except
32 Alternative F would result in negligible change in regional income, less than 0.6%. The largest
33 potential decrease would be 1.1% under Alternative F because that alternative has higher releases
34 in the spring and lower releases through the summer every year, and consequently slightly
35 different reservoir levels in the summer months.
36
37

38 **4.9.1.7 Maintain Tribal Water Rights and Supply**
39

40 Reclamation is committed to operating Glen Canyon Dam so that all water obligations
41 are met, including those to Tribes. Lake Powell supplies water to both the Navajo Chapter of
42 LeChee and the City of Page, Arizona, which share a water intake system (NPS 2009b).
43 Currently, two intakes provide water. There is an intake on the face of the dam at 3,480 ft above
44 mean sea level and a second intake off the penstocks to Units 7 and 8 at 3,470 ft above mean sea
45 level. In the current configuration, the minimum pool elevation necessary to supply LeChee and
46 Page is 3,470 ft above mean sea level. The minimum power pool elevation is 3,490 ft above

1 mean sea level, well above the water intakes (Grantz 2014). Plans now under consideration call
2 for a new, lower intake at 3,373 ft above mean sea level. The modeling results for all of the
3 alternatives show Lake Powell levels remaining above the existing and proposed intakes for the
4 entire 20-year period (see Appendix J). The lowest pool level projected is 3,480.3 ft above mean
5 sea level, about the level of the intake on the dam face and 10 ft above the penstock intake.
6
7

8 **4.9.1.8 LTEMP Process**

9
10 Tribes have been involved in the LTEMP development process and will continue to be
11 involved in the implementation of LTEMP. Tribes have routinely expressed concern regarding
12 how LTEMP decisions are made rather than what decision is made, the genuine incorporation of
13 Tribal input, and the importance of learning to improve management over time. They have
14 favored an experimental approach resulting in adaptive management.
15

16 Over the course of the development of the LTEMP DEIS, Reclamation and the NPS have
17 sought to incorporate Tribal input into the LTEMP process. Cooperating and consulting Tribes
18 were included in Cooperating Agency and stakeholder meetings. Reclamation and NPS have also
19 held Tribal meetings, workshops, conference calls, and webinars. Various documents related to
20 the development of the LTEMP DEIS have been provided to the Tribes for their review and
21 input. When requested, there have been face-to-face meetings with the Tribes. Tribes were given
22 the opportunity to contribute to the Tribal lands, affected environment, and environmental
23 consequence sections of the DEIS, and Tribal views have been incorporated throughout this
24 DEIS. A complete summary of Tribal consultation efforts is provided in Section 5 and
25 Appendix N.
26
27

28 **4.9.2 Analysis Methods**

29
30 Two main issues emerged in analyzing how the proposed action would be likely to affect
31 Tribal resources in the Canyons: (1) How would alternatives affect the continued existence of
32 Tribal resources in the Canyons? and (2) How would alternatives affect the sacred integrity of
33 and Tribal connections to the Canyons? Since the Tribes are the best judges of how the
34 alternatives would affect them and because some Tribal resources are sacred and their locations
35 confidential, the answers to these questions require input from the Tribes. The analysis presented
36 here is based mainly on input from the Tribes, augmented with analysis of quantifiable impacts.
37

38 Input from the Tribes was sought and continues to be sought in a number of ways.
39 Initially, NPS and Reclamation identified 43 federally recognized Tribes with potential historical
40 and cultural ties to the Colorado River and its Canyons and invited them to participate in the
41 LTEMP DEIS process, as either Cooperating Agencies or consulting parties. NPS and
42 Reclamation conducted meetings with groups of cooperating and consulting Tribes; these
43 meetings included workshops, teleconferences, webinars, and face-to-face meetings with Tribal
44 authorities in efforts to fully identify Tribal concerns about impacts of alternatives on resources.
45 The agencies also consulted with Tribes during Cooperating Agency meetings. Tribes that chose
46 to become Cooperating Agencies also were given the opportunity to contribute to the writing of

1 the DEIS. Chapter 5 and Appendix N provide descriptions and other information for the
2 consultation process. Goals for resources of Tribal concern were developed from information
3 obtained at these meetings, and Tribes had an opportunity to review, edit, and contribute
4 additional information and concerns. Where possible, potential impacts on these resource goals
5 were determined quantitatively, and modeling was used to quantify impacts. Modeling and
6 analysis incorporated analyses from other resource areas such as aquatic resources, riparian
7 vegetation, and economics. Tribes were invited to meetings where the results of the modeling
8 were presented, and they were given a chance to ask questions and contribute comments.
9

10 Qualitative assessments of impacts were based on written information produced by or for
11 the Tribes. Significant insight into Tribal priorities came from the Tribes that regularly monitor
12 the state of resources in the Canyons that they consider significant. Tribal monitoring reports
13 from the Hopi (Yeatts and Brod 1996; Dongoske 2001; Yeatts and Huisinga 2006, 2009, 2010,
14 2011, 2012, 2013), Hualapai (Jackson et al. 2001; Jackson-Kelly et al. 2009, 2010, 2011, 2013),
15 Navajo (NNHPD 2012), Southern Paiute (Austin et al. 1999; Drye et al. 2000, 2001, 2002, 2006;
16 Bullets et al. 2003, 2004, 2008, 2010, 2011, 2012; Snow et al. 2007), and Zuni
17 (Dongoske 2011a) were consulted for information on sites and resources of importance, as were
18 ethnographies produced for the Tribes during previous related National Environmental Policy
19 Act of 1969, as amended (NEPA) analyses (Ferguson and Lotenberg 1998; Lomaomvaya et al.
20 2001; Roberts et al. 1995; Yeatts and Huisinga 2003; Stoffle et al. 1994, 1995; Hart 1995).
21
22

23 **4.9.3 Summary of Impacts**

24

25 A summary of the impacts of the LTEMP alternatives on Tribal resources is presented in
26 Table 4.9-2. In general, it is anticipated that there will be limited impacts on places and resources
27 from the proposed action and the impacts that are anticipated do not vary greatly among the
28 alternatives. Flow-related impacts on traditional cultural places include inundation by high flows
29 (i.e., flows above the normal maximum operating flow of 25,000 cfs), resulting in erosion and
30 temporary loss of access to such features as springs. Inundation impacts are temporary and can
31 be mitigated through communication between Reclamation and the Tribes regarding scheduled
32 high flows. The potential for the inundation of historic properties and erosion of terraces where
33 historic properties are located is discussed above in Section 4.8. It is anticipated that traditional
34 cultural resources most directly affected by flows would be riparian vegetation and fishes. Flow
35 impacts on culturally important terrestrial wildlife would be minimal and do not vary among
36 alternatives (see Section 4.7).
37

38 Non-flow actions include trout removal and vegetation management. Proposed
39 experimental vegetation management activities include the removal of nonnative species,
40 clearing vegetation to expose sand for camping and distribution by wind, removing encroaching
41 vegetation from campsites, and replacing removed nonnative species with native species, many
42 of which have cultural importance to the Tribes. Vegetation management has the potential for
43 both beneficial and adverse impacts (see Section 4.9.4). Increasing campable area by clearing
44 campsites may not be seen as positive by Tribes that consider the Canyons a sacred space and are
45 concerned with visitors disrespecting and interfering with important ceremonial and other
46
47

1 **TABLE 4.9-2 Summary of Impacts of LTEMP Alternatives on Tribal Resources**

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Operations would result in no change in the amount of sand available for wind transport to cultural resource sites; a negligible loss of riparian diversity; a small loss of wetlands and no impact to Tribal water and economic resources. No TMFs, but mechanical trout removal could be triggered. After 2020, potential adverse impact to culturally important archaeological sites.	Compared to Alternative A, operations would result in a slight increase in the amount of sand available for wind transport to cultural resource sites except during hydropower improvement flows when there would be a slight decrease. There would be a slight loss in riparian diversity and slightly more loss in wetlands. There would be no impact on Tribal water and economic resources. TMFs and mechanical trout removal could be triggered.	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.	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.	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.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites but would result in an increase in the potential for river runners to explore and potentially damage places of cultural importance during May and June. The greatest loss of wetlands, largest increase in invasive species, and lowest riparian plan diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs or mechanical trout removal.	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.

4-243

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Places							
Visitation of culturally significant sites	No change in the potential for recreationists to visit culturally significant sites	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Slight increase in the potential for recreationists to visit culturally significant sites in May and June	Same as Alternative A
Availability of sand for wind transport to protect culturally important archaeological sites	Negligible change in wind transport of sand; some increase in sand from HFEs until 2020, when HFEs are discontinued; potential adverse impact due to reduction in sediment availability after 2020	Similar to Alternative A either with slight potential increase (+7%) from HFEs continuing over entire LTEMP period or slight decrease (-10%) from Alternative A due to hydropower improvement flow tests.	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+137%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to protect cultural resource sites (+139%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+96%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+88%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+193%), resulting from increase in frequency of HFEs

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Resources							
Riparian plant diversity	Slight loss of riparian plant diversity (0.97 diversity index)	Similar to Alternative A (0.99 diversity index)	Decrease in riparian plant diversity compared to Alternative A (0.75 diversity index)	Similar to Alternative A (0.97 diversity index)	Similar to Alternative A (0.95 diversity index)	Lowest riparian plant diversity (0.68 diversity index) compared to Alternative A; largest acreage of invasive plants	Decrease in riparian plant diversity compared to Alternative A (0.83 diversity index)
Retention of wetlands (existing marsh is less than 5 ac total)	Approximately 3.6 ac retained; 28% loss.	Approximately 4 ac retained; 8% more than Alternative A. Under hydropower improvement, flows wetlands loss would be greater.	Approximately 1.25 ac retained; 47% less than Alternative A. Second-largest area of wetlands loss across alternatives.	Approximately 4.2 ac retained; 12% more than Alternative A. Least loss of wetlands across alternatives.	Approximately 3.1 ac retained; 10% less than Alternative A.	Approximately 0.7 ac retained; 58% less than Alternative A. Largest area of wetlands loss across alternatives.	Approximately 1.5 ac retained; 30% less than Alternative A. Third-largest area of wetlands loss.
Frequency of TMFs	No TMFs	TMFs expected in 3 of 20 years	TMFs expected in about 6 of 20 years	TMFs expected in 8 of 20 years	TMFs expected in 3 of 20 years	No TMFs	TMFs expected in 11 of 20 years
Frequency of mechanical removal of trout	Trout removal expected in <1 of 20 years	Trout removal expected in <1 of 20 years	Trout removal expected in about 1 to 3 of 20 years	Trout removal expected in about 2–3 of 20 years	Trout removal expected in about 1 or 2 of 20 years	No trout removal	Trout removal expected in 3 of 20 years
Impacts on culturally important wildlife	Negligible adverse impact effects on culturally important wildlife	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A

4-245

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Economic and Water Resources</i>							
Impact on Tribal flat-water or whitewater rafting services	No impact on flat-water or whitewater runs	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Impact on Tribal land-based vendors	No impact on land-based vendors	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Impact on Tribal Lake Powell marina	No change from current condition	No difference from Alternative A	Negligible difference from Alternative A (<0.6%)	Negligible difference from Alternative A (<0.6%)	Negligible difference from Alternative A (<0.6%)	Slight decrease in marina income (1.1%)	Negligible difference from Alternative A (<0.6%)
Water supply	Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A

4-246

1 cultural activities. All LTEMP alternatives would have the same overall level of visitation, set by
2 the number of permits, so effects would be negligible in terms of a difference from No Action.
3 Also there are potential positive effects that could result from using plants as barriers, closing off
4 trails to culturally sensitive sites, and increasing native plants in restoration areas that are
5 important to Tribes. Removing vegetation to open up sandy beaches has the potential for
6 allowing the wind transport of fine sediment to higher elevations and potentially shielding
7 archaeological sites from erosion. These impacts would not vary among the alternatives. Lethal
8 removal of trout has been identified by the Zuni with the support of other affiliated Tribes as
9 having an adverse effect on the TCP of the Grand Canyon, particularly when it takes place in
10 proximity to the confluence of the Colorado River and the Little Colorado River, an area of
11 special significance to the Zuni (Dongoske 2011b), the Hopi (Yeatts and Huisinga 2013), and the
12 Navajo (Roberts et al. 1995). The lethal mechanical removal of trout and/or TMFs would be
13 considered a significant adverse impact by some Tribes; however, if done in conjunction with
14 mandated consultation with the Tribes, the impact may be reduced through beneficial uses and
15 other practices that have been used for the Bright Angel fish removal efforts. For a discussion of
16 alternative specific impacts see Section 4.9.4.

17
18 As discussed in Section 3.9, many of the Tribes that have been involved with this DEIS
19 consider portions of the Colorado River and its tributaries, the Canyons through which they flow,
20 as well as elements within the river and Canyon corridors, as a TCP or part of a TCP. Any
21 impact on any cultural place or cultural resource—be it an archaeological site, sacred place,
22 traditional collection area, important plant or animal, or other element considered a TCP or
23 contributing element to a TCP—is also considered an impact on the TCP, because these
24 resources add to the overall traditional value of the TCP for these Tribes. As previously
25 discussed, many Tribes have their own monitoring programs whereby resources and sites of
26 importance are monitored, the health of the Canyon is examined, sacred sites are visited, and
27 respects are paid to the Canyon and its resources. Any effect on the Canyons and their resources
28 will likely be evaluated by each Tribe during the monitoring assessments. The Zuni in particular
29 have stated that any action within the Grand Canyon will have to be assessed by the Zuni people
30 for adverse effects that may be experienced in the Zuni Pueblo itself.

31 32 33 **4.9.4 Alternative-Specific Impacts**

34
35 This section presents the impacts of the LTEMP alternatives on the Tribal resource goals
36 presented in Section 4.9.1. Impacts are based on both quantitative and qualitative indicators of
37 the status of resources that Tribes have indicated are culturally important. Factors considered
38 include the state of riparian plant communities, riparian and terrestrial wildlife, and aquatic
39 resources. Also considered are the time Canyon visitors spend off the river, potentially impacting
40 traditional cultural places and economic opportunities for commercial Tribal river runners.

41 42 43 **4.9.4.1 Alternative A (No Action Alternative)**

44
45 Under Alternative A, the No Action Alternative, the modified fluctuating flows as
46 defined in the 1996 ROD for the operation of Glen Canyon Dam would continue. Existing

1 operations and recent decisions would be maintained. The existing HFE protocol and nonnative
2 fish control actions and experimentation would continue until 2020 as specified in existing EAs.
3 The HFE protocol EA (Reclamation 2011b) projected that access to and use of certain cultural
4 properties could possibly be altered due to inundation in the area directly affected by an HFE.
5 Less sand would be moved from Marble Canyon downstream under this alternative than under
6 any other and it has the lowest sand load index score, which suggests there would be less
7 building of sandbars, resulting in less sand being available for windborne transport to culturally
8 important sites.

9
10 Alternative A is likely to result in a relatively even proportional distribution of plant
11 community types, but a slight loss in plant community diversity. Modeling results suggest that
12 3.6 ac of wetland habitat will remain at the end of the 20-year LTEMP period, a decrease of 28%
13 from the current wetland acreage (Section 4.6). An estimated 4.6 ac of wetlands occurs
14 downstream from the dam.

15
16 Testing of TMFs is allowed under Alternative A, but since there has not been a decision
17 to implement these flows, they are not considered a regular action under this alternative.
18 Modeling of trout numbers suggests that mechanical removal trips would only rarely be
19 triggered, resulting in the fewest removal trips of any alternative where mechanical removal is
20 allowed, in part because removal actions would expire in 2020. As indicated by lack of
21 significant changes in the riparian plant communities and the mobility of larger animals, impacts
22 on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer,
23 snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi
24 Tribe)—are likely to be negligible and would not differ among the alternatives (Section 4.7).

25
26 Time off river under this alternative would be the same as all other alternatives except
27 Alternative F (Section 4.8.3).

28
29 Income from Hualapai river-running is not expected to diminish and would not be
30 affected by the alternatives. The Canyons are expected to continue to draw tourists who would
31 patronize land-based Tribal tourist facilities and Native American craft vendors. These would not
32 be affected by the flow alternatives. There would be no effect to the Navajo marina under this
33 alternative (Sections 4.2 and 4.14.2.1; Reclamation 2011a).

34
35 In summary, under Alternative A, there would be a relatively even distribution of plant
36 community types, but a slight loss in plant diversity and wetland acreage. Trout removal trips are
37 expected to be triggered in 1 year out of 20, the lowest expected number of trips among
38 alternatives, which represents no change from current conditions. The availability of sand for
39 wind transport could provide some benefit to some places of traditional cultural importance due
40 to HFEs until 2020 when the HFE protocol expires, at which point these areas could experience
41 an adverse impact due to lack of available sediment for wind transport. However, places of
42 traditional cultural importance are present throughout the Canyons and vary in nature. Wind-
43 transported sand may not always be considered a benefit for these resources. As stated in
44 Section 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites
45 on the terraces remains unknown. Sediment can also be removed from archaeological sites by
46 wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural

1 place or resource. There would be no change in the potential for recreationists to visit culturally
2 significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife
3 are expected to be negligible. There would be no change from current conditions related to Tribal
4 flat-water or whitewater rafting services, Tribal land-based vendors, marinas operated by Tribal
5 enterprises, or Navajo Nation water supply. Any impact on a Tribally important cultural place or
6 resource is also considered an impact on a Tribe's TCP.

9 **4.9.4.2 Alternative B**

10
11 Alternative B would follow the same monthly water release volumes as Alternative A,
12 but there would be greater fluctuations in 10 months of the year and increased down-ramp rates.
13 Under this alternative, HFEs would be implemented over the entire 20-year LTEMP period, but
14 they are limited to no more than one every other year. There is greater daily flow fluctuation than
15 in Alternative A for most months. Hydropower improvement flows—operations with wider
16 fluctuations in high electrical demand months—would be tested in 4 years when the annual
17 release volume is ≥ 8.23 maf. TMFs would be tested and implemented if successful.

18
19 This alternative is likely to result in the maintenance of current levels of evenness and
20 diversity of plant community distribution; slightly higher plant diversity is expected than under
21 Alternative A. Due to a lack of extended high or low flows that scour or desiccate wetlands,
22 approximately 4 ac of wetlands would be retained under Alternative B, 8% more than under
23 Alternative A (Section 4.6), except under the hydropower improvement flows, in which case
24 there would be increased loss of wetlands. An estimated 4.6 ac of wetlands occurs downstream
25 from the dam.

26
27 The wider daily fluctuations under Alternative B would reduce the potential for bar-
28 building, making less sand available for windborne transport to culturally important places
29 relative to normal operations under Alternative B. Under typical operations, more sediment
30 would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected
31 in the Sand Load Index would be slightly greater (+7%) than under Alternative A, unless
32 hydropower improvement flows are included, in which case the Sand Load Index would be
33 slightly less than under Alternative A (-10%).

34
35 Under this alternative, TMFs are expected to occur in about three of the 20 LTEMP
36 years. This alternative and Alternative E likely would have the fewest TMFs among the
37 alternatives that allow TMFs (Alternatives A and F do not). Low numbers of TMFs result from
38 lower numbers of trout recruits in the Glen Canyon reach. Low trout numbers result from higher
39 daily fluctuations and fewer spring HFEs. When trout numbers are low, mechanical removal is
40 triggered in fewer years.

41
42 Based on the lack of significant changes in the riparian plant communities and the
43 mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to
44 Tribes, such as big horn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an
45 important group of birds for the Hopi Tribe)—are likely to be negligible and not to differ across
46 the alternatives (Section 4.7).

1 Time off river under this alternative would be the same as all other alternatives except
2 Alternative F (see Section 4.8.3).

3
4 Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or
5 Navajo Nation water supply would be the same as under Alternative A. Marinas operated by
6 Tribal enterprises would experience no loss in income when compared to Alternative A.

7
8 In summary, under Alternative B, current wetland acreage is expected to be retained and
9 plant diversity would be slightly higher than under Alternative A, except under hydropower
10 improvement flows, which would result in greater loss of wetlands. TMFs are expected to be
11 triggered in 3 years out of 20; while trout removal trips are expected to potentially be triggered,
12 if at all, in 1 year out of 20. The availability of sand for wind transport to potentially protect
13 some places of traditional cultural importance would somewhat increase relative to Alternative A
14 because HFEs would occur over the entire LTEMP period. However, the high fluctuations of
15 hydropower improvement flow would potentially decrease the availability of sand. Places of
16 traditional cultural importance are present throughout the Canyons and vary in nature. Wind-
17 transported sand may not always be considered a benefit for these resources. As stated in Section
18 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites on the
19 terraces remains unknown. Sediment can also be removed from archaeological sites by wind and
20 rain, a factor that could lead to loss of integrity of a traditionally important cultural place or
21 resource. There would be no change in the potential for recreationists to visit culturally
22 significant sites. Impacts to Tribally important riparian plant communities and terrestrial wildlife
23 are expected to be negligible. Economic effects on Tribal tourist enterprises would be the same
24 as under Alternative A. Any impact on a Tribally important cultural place or resources is also
25 considered an impact on a Tribe's TCP.

26 27 28 **4.9.4.3 Alternative C**

29
30 Under Alternative C, the highest water release volumes would occur in the high electric
31 demand months of December, January, and July, with lower volumes from August through
32 November to conserve sediment inputs during the monsoon period. The HFE protocol would be
33 followed for the entire 20-year period, and some additional HFEs would be allowed. Proactive
34 spring HFEs would be tested in years with a high volume of flow (>10 maf). Compared to
35 Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for
36 sandbar building as reflected in the Sand Load Index would be greater (+137%), making more
37 sand available for windborne transport to cultural sites (Section 4.3).

38
39 Operations under this alternative are expected to result in relatively low plant community
40 diversity and evenness. High flows followed by growing season lows are likely to result in more
41 loss of diversity than under Alternative A (Section 4.6). This alternative is expected to retain
42 approximately 1.25 ac of wetlands, 47% less than that retained under Alternative A. This
43 alternative results in more wetland loss than any other alternative except Alternative F. An
44 estimated 4.6 ac of wetlands occurs downstream from the dam.

45

1 TMFs are expected to be triggered in about 6 out of 20 years under this alternative
2 because of the relatively higher number of trout expected to be produced (Section 4.5).
3 Mechanical trout removal is expected to be triggered in few if any of the 20 years modeled.
4

5 As under other alternatives, because of the types of changes expected in the riparian plant
6 communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—
7 including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and
8 yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be
9 negligible and not to differ across the alternatives (Section 4.7).
10

11 Time off river under this alternative would be the same as all other alternatives except
12 Alternative F (see Section 4.8.3).
13

14 Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or
15 Navajo Nation water supply would be the same as under Alternative A. Marinas operated by
16 Tribal enterprises would experience a negligible loss in income when compared to Alternative A
17 (<0.6%).
18

19 In summary, under Alternative C, the diversity of riparian plant communities is expected
20 to decrease, and this alternative is expected to result in the second-largest area of wetland loss
21 when compared to Alternative A. TMFs are expected to be triggered in 6 out of 20 years, and
22 trout removal trips could potentially to be triggered in 3 out of 20. Under Alternative C, there
23 would be a slight increase in the potential for wind transport of sand to protect some places of
24 traditional cultural importance when compared to Alternative A. However, places of traditional
25 cultural importance are present throughout the Canyons and vary in nature. Wind-transported
26 sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the
27 actual extent to which current sediment levels can stabilize the archaeological sites on the
28 terraces remains unknown. Sediment can also be removed from archaeological sites by wind and
29 rain, a factor that could lead to loss of integrity of a traditionally important cultural place or
30 resource. There would be no change in the potential for recreationists to visit culturally
31 significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife
32 are expected to be negligible. Economic effects on Tribal tourist enterprises would be the same
33 as under Alternative A, except for Tribally operated marinas, which would experience a
34 negligible drop in income. Any impact on a Tribally important cultural place or resources is also
35 considered an impact on a Tribe's TCP.
36
37

38 **4.9.4.4 Alternative D (Preferred Alternative)** 39

40 Alternative D adopts characteristics of Alternatives C and E to achieve sediment retention
41 characteristics and other resource benefits while reducing impacts on the value of hydropower
42 generation and capacity, when compared to Alternatives C and E. Like Alternatives C and E,
43 Alternative D includes a number of condition-dependent flow and non-flow actions that may be
44 triggered by resource conditions. Alternative D differs from the other two in the specific trigger
45 conditions and the actions that would be taken. Compared to Alternative A, more sediment
46 would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected

1 in the Sand Load Index would be greater (+139%), making more sand available for windborne
2 transport to cultural sites (Section 4.3).

3
4 Under Alternative D, riparian plant community diversity and evenness would be virtually
5 the same as under Alternative A and similar to Alternative E. These alternatives would result in
6 only a slight loss of plant community diversity. There would be on average an overall loss of
7 invasive species; both tamarisk and arrowweed would decrease under Alternative D. There
8 would be somewhat less loss of tamarisk under Alternative D than under Alternatives A or E.
9 Repeated extended high flows can remove tamarisk and arrowweed. The low number of growing
10 season extended low flows would limit tamarisk establishment and the shifting of wetland
11 communities to arrowweed (Section 4.6.3.4).

12
13 Approximately 4.2 ac of wetlands would be retained under Alternative D, 12% more than
14 under Alternative A. This alternative would result in the least amount of wetland loss of all
15 alternatives. Greater wetland acreage is associated with greater plant community diversity. Low
16 numbers of extended low flows during the growing season would limit the occurrence of wetland
17 communities shifting to arrowweed. An estimated 4.6 ac of wetlands occurs downstream from
18 the dam.

19
20 Spring HFEs, which stimulate the food base, and steady summer flows are factors that
21 tend to result in trout population growth. Spring HFEs would be more common under
22 Alternative D than under Alternative A, and summer daily fluctuations would be slightly less
23 under Alternative D than under Alternative A. Under Alternative D, TMFs are expected to be
24 triggered in about 8 out of 20 years. This would be more often than under any alternative except
25 Alternative G, partly because TMFs could be triggered during years in which the production of
26 young-of-the-year rainbow trout in the Glen Canyon reach is anticipated to be high. Overall,
27 because TMFs are expected to reduce the number of fish in the trigger reach, mechanical
28 removal could be triggered in fewer years. Under Alternative D, modeling suggests that trout
29 removal would occur in about 2 to 3 out of 20 years, more often than under any other alternative
30 except Alternative G.

31
32 As under other alternatives, because of the types of changes expected in riparian plant
33 communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—
34 including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and
35 yellow-feathered nesting birds—are likely to be negligible and not to differ across the
36 alternatives (Section 4.7).

37
38 Time off river under this alternative would be the same as all other alternatives except
39 Alternative F (Section 4.8.3).

40
41 Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or
42 Navajo Nation water supply would be the same as under Alternative A. Marinas operated by
43 Tribal enterprises would experience a negligible loss in income when compared to Alternative A
44 (<0.6%).

1 In summary, under Alternative D, there would be a relatively even distribution of plant
2 community types, but a slight loss in plant diversity, similar to Alternative A. The least amount
3 of wetland acreage loss would occur under this alternative. TMFs are expected to be triggered in
4 8 years out of 20, and trout removal trips could potentially be triggered 3 years out of 20. Under
5 Alternative D, there would be a slight increase in the potential for wind transport of sand to
6 protect some places of traditional cultural importance when compared to Alternative A.
7 However, places of traditional cultural importance are present throughout the Canyons and vary
8 in nature. Wind-transported sand may not always be considered a benefit for these resources. As
9 stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the
10 archaeological sites on the terraces remains unknown. Sediment can also be removed from
11 archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally
12 important cultural place or resource. There would be no change in the potential for recreationists
13 to visit culturally significant sites. Impacts on Tribally important riparian plant communities and
14 terrestrial wildlife are expected to be negligible. Economic effects on Tribal tourist enterprises
15 would be the same as under Alternative A, except for Tribally operated marinas, which would
16 experience a negligible drop in income. Any impact on a Tribally important cultural place or
17 resources is also considered an impact on a Tribe's TCP.

4.9.4.5 Alternative E

22 Like Alternatives C and D, Alternative E includes a number of condition-dependent flow
23 and non-flow actions that would be triggered by resource conditions. Alternative E differs from
24 the other two in the specific trigger conditions and the actions that would be taken. Under
25 Alternative E, the relatively high number of HFES projected would result in a higher Sand Load
26 Index (+96%) and significantly more sandbar building potential than under Alternative A,
27 making more sand available for windborne dispersal to culturally important places.

29 This alternative would result in a slightly less diverse and even distribution of plant
30 community types than under Alternatives A, B, and D, but more diversity and evenness than
31 under Alternatives C, F, or G. This alternative is expected to retain approximately 3.1 ac of
32 wetlands, 10% less relative to Alternative A. An estimated 4.6 ac of wetlands occurs downstream
33 from the dam.

35 TMFs would be triggered in about the same number of years as under Alternative B.
36 Fewer TMFs are expected because the number of trout in the Glen Canyon reach is expected to
37 be lower under this alternative as a result of higher summer fluctuation levels and fewer spring
38 HFES. Mechanical removal would be triggered in about 1 or 2 out of 20 years.

40 Because of the types of changes expected in riparian plant communities and the mobility
41 of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes,
42 such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely
43 to be negligible and not to differ across the alternatives (Section 4.7).

45 Time off river under this alternative would be the same as all other alternatives except
46 Alternative F (Section 4.8.3).

1 Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or
2 Navajo Nation water supply would be the same as under Alternative A. Marinas operated by
3 Tribal enterprises would experience a negligible loss in income when compared to Alternative A
4 (<0.6%).
5

6 In summary, under Alternative E, diversity and evenness of plant community types would
7 be slightly less than under Alternatives A, B, and D, but slightly more than under Alternatives C,
8 F, or G. This alternative would retain more wetland acreage than Alternatives F, G, and C. TMFs
9 are expected to be triggered in 3 years out of 20, and trout removal trips could potentially be
10 triggered 2 years out of 20. Under Alternative E, there is a slight increase in the potential for
11 wind transport of sand to protect some places of traditional cultural importance when compared
12 to Alternative A. However, places of traditional cultural importance are present throughout the
13 Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for
14 these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can
15 stabilize the archaeological sites on the terraces remains unknown. Sediment can also be
16 removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity
17 of a traditionally important cultural place or resource. Impacts on Tribally important riparian
18 plant communities and terrestrial wildlife are expected to be negligible. There would be no
19 change in the potential for recreationists to visit culturally significant sites. There would be no
20 impact on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo
21 Nation water supply. Marinas operated by Tribal enterprises would experience a negligible drop
22 in income. Any impact on a Tribally important cultural place or resources is also considered an
23 impact on a Tribe's TCP.
24
25

26 **4.9.4.6 Alternative F**

27
28 Alternative F is designed to re-create a more natural (pre-dam) flow pattern while
29 limiting sediment transport and providing lower, stable base flows in summer, fall, and winter,
30 and warmer temperatures in the summer. It allows both spring and fall HFES, which should
31 significantly increase the deposition and retention of sediment relative to Alternative A.
32 Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and
33 the potential for sandbar building as reflected in the Sand Load Index would be greater (+88%),
34 making more sand available for windborne transport to cultural sites (Section 4.3).
35

36 This alternative would result in the lowest degree of evenness and diversity and the
37 greatest spread of tamarisk-dominated communities. This alternative would have high flows that
38 spread tamarisk seeds followed by growing season low flows, which would allow seedlings to
39 establish themselves. Similarly, this alternative is expected to result in the greatest amount of
40 wetland loss of any alternative, retaining only 0.7 ac of wetlands, 58% less than under
41 Alternative A. An estimated 4.6 ac of wetlands occurs downstream from the dam.
42

43 This alternative includes neither mechanical removal nor TMFs and would thus allow
44 nature to take its course regarding the interaction of humpback chub and nonnative trout. The
45 steady flows and frequent spring HFES of this alternative are expected to produce larger numbers
46 of trout relative to most other alternatives.

1 Because of the types of changes expected in the riparian plant communities and the
2 mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to
3 Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are
4 likely to be negligible and not to differ across the alternatives (Section 4.7).

5
6 Under this alternative, visitors to the Canyons would spend slightly more time off the
7 river than under any of the other alternatives (Section 4.8.3).

8
9 Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or
10 Navajo Nation water supply would be the same as under Alternative A. Marinas operated by
11 Tribal enterprises would experience a 1.1% loss of income (Section 4.14.2.1).

12
13 In summary, under Alternative F, plant diversity would be at its lowest, wetland loss
14 would be at its highest, and the largest acreage of invasive species would occur. There would be
15 no TMFs or mechanical trout removal trips under this alternative.

16
17 Under Alternative F, there would be a slight increase in the potential for wind transport of
18 sand to protect some places of traditional cultural importance when compared to Alternative A.
19 However, places of traditional cultural importance are present throughout the Canyons and vary
20 in nature. Wind-transported sand may not always be considered a benefit for these resources. As
21 stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the
22 archaeological sites on the terraces remains unknown. Sediment can also be removed from
23 archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally
24 important cultural place or resource. There would be a slight increase in the potential for
25 recreationists to visit and potentially damage culturally significant sites during May and June.
26 Impacts to Tribally important riparian plant communities and terrestrial wildlife are expected to
27 be negligible. There would be no impact on Tribal flat-water or whitewater rafting services,
28 Tribal land-based vendors, or Navajo Nation water supply. Marinas operated by Tribal
29 enterprises would experience a slight drop in income under this alternative. Any impact on a
30 Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

31 32 33 **4.9.4.7 Alternative G**

34
35 Alternative G targets the conservation of sediment through steady, equal monthly release
36 volumes that would maximize retention of sediment, and the largest number of HFEs of any
37 alternative, some with extended duration, which would distribute and retain sediment at higher
38 elevations. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs
39 level and the potential for sandbar building as reflected in the Sand Load Index would be greater
40 (+193%), making more sand available for windborne transport to cultural sites (Section 4.3).

41
42 With more high flows, it is likely that this alternative would result in somewhat less
43 diversity and evenness of plant communities than under Alternative A, but more diversity and
44 evenness than under Alternatives C and F. The alternative would retain approximately 1.5 ac of
45 wetlands, 30% less than Alternative A. Mean wetland acreage would be lower than that of

1 Alternatives A, B, D, and E, but above that of Alternatives C and F (see Appendix J). An
2 estimated 4.6 ac of wetlands occurs downstream from the dam.

3
4 The steady summer flows and spring HFEs that characterized this alternative create
5 favorable conditions for the growth of the trout population. As a consequence, TMFs are
6 expected to occur more often under this alternative (11 out of 20 years) than under any other.
7 Mechanical removal would also occur more often under this alternative than any other, on
8 average about 3 out of 20 years.

9
10 Because of the types of changes expected in the riparian plant communities and the
11 mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to
12 Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are
13 likely to be negligible and not to differ across the alternatives (Section 4.7).

14
15 Time off river under this alternative would be the same as all other alternatives except
16 Alternative F (Section 4.8.3).

17
18 Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, and
19 Navajo Nation water supply would be the same as under Alternative A. Marinas operated by
20 Tribal enterprises would experience a negligible loss in income when compared to Alternative A
21 (<0.6%).

22
23 In summary, under Alternative G, there would be a decrease in riparian plant diversity,
24 and the third-largest wetland acreage loss across alternatives would occur. TMFs are expected to
25 be triggered in 11 out of 20 years, and trout removal trips could potentially to be triggered 3 out
26 of 20 years.

27
28 Under Alternative G, there would be a slight increase in the potential for wind transport
29 of sand to protect some places of traditional cultural importance when compared to Alternative
30 A. However, places of traditional cultural importance are present throughout the Canyons and
31 vary in nature. Wind-transported sand may not always be considered a benefit for these
32 resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can
33 stabilize the archaeological sites on the terraces remains unknown. Sediment can also be
34 removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity
35 of a traditionally important cultural place or resource. Impacts on Tribally important riparian
36 plant communities and terrestrial wildlife are expected to be negligible. There would be no
37 change in the potential for recreationists to visit culturally significant sites when compared to
38 Alternative A. There would be no impact on Tribal flat-water or whitewater rafting services,
39 Tribal land-based vendors, or Navajo Nation water supply. Marinas operated by Tribal
40 enterprises would experience a negligible drop in income. Any impact on a Tribally important
41 cultural place or resources is also considered an impact on a Tribe's TCP.

4.10 RECREATION, VISITOR USE, AND EXPERIENCE

This section presents the potential impacts of LTEMP alternatives on recreation, visitor use, and experience. Background information on the resources or resource attributes included in this analysis can be found in Section 3.10. There are also references to Sections 4.5 (Aquatic Ecology), Section 4.6 (Plant Communities), Section 4.14 (Socioeconomics and Environmental Justice), and the Recreation Economic Analysis in Appendix L, as they apply to visitor use and experience.

4.10.1 Analysis Methods

The analysis of impacts on recreation, visitor use, and experience downstream of Glen Canyon Dam was based on assessment of alternative-specific differences in 10 indicators that were based on six quantitative metrics developed using recreational findings in published papers and reports, and quantified based on alternative-specific flow characteristics. The metrics were developed through consultation with subject matter experts and with consideration of comments from Cooperating Agencies.

Four of the metrics address issues important to visitor use and experience in GCNP, while the other two metrics focus on the Glen Canyon reach between the dam and Lees Ferry. Some information used for the assessment is not from measures of specific factors but is qualitative in nature. Most metrics were created as indices with values ranging from 0 to 1, where 1 is the optimal condition for that resource, and 0 represents the lowest possible value. An index with a relative scale was used because it was often impossible to quantify the condition of the resource, but it was possible to generate a relative scale that reflected that condition. For example, there is no current methodology that defines how specific camping areas in GCNP might respond to HFES, but there is a basis for making conclusions about which conditions are likely to favor a general increase in camping area in the park. The exception to the 0 to 1 scale is the Glen Canyon Rafting Metric, which measures the number of potential lost rafting trips. All of the metrics except the Glen Canyon Rafting Metric are seasonally weighted to reflect seasonal differences in recreational use, with more weight given to conditions in the peak recreation period than in periods with less use. More information including assumptions and limitations of these metrics is in Appendix J. The six recreation-specific metrics are as follows:

Issue: How do the alternatives affect recreation, visitor use, and experience?

Impact Indicators:

- Fish size and catch rate
- Flow fluctuation levels
- Navigability and safety
- Lost visitor opportunities
- Camping and recreation facilities on old sediment terraces
- Campsite area
- Campsite crowding
- Encounters with other groups
- Lake recreation
- Sediment impacts on Tribal recreation program in lower Grand Canyon

- 1 • *Camping Area Index*—Accounts for optimal campsite area building and
2 maintenance flows and sediment load (also used as input to the assessment of
3 campsite crowding).
- 4
- 5 • *Time Off-River Index*—Relates the level of flows to visitors being able to
6 spend time ashore visiting attractions.
- 7
- 8 • *Fluctuation Index*—Based on combinations of flows and fluctuations
9 identified as preferable by experienced boat operators.
- 10
- 11 • *Navigation Index*—Based on the percentage of time minimum daily flows are
12 less than 8,000 cfs (also used as input to the assessment of campsite crowding
13 and encounters with other groups).
- 14
- 15 • *Glen Canyon Rafting Metric*—Estimates the number of visitors unable to
16 participate in day rafting in Glen Canyon due to high flows; the metric is the
17 mean annual number of lost visitor opportunities.
- 18
- 19 • *Glen Canyon Inundation Index*—Accounts for flows that impact recreational
20 sites and recreational uses within the Glen Canyon reach.
- 21

22 In the discussions below, the anticipated impacts of the alternatives are compared to the
23 effects of Alternative A, the No Action Alternative. Impacts on recreation were developed using
24 these metrics as well as published literature to evaluate how recreation would be affected by the
25 alternatives. Information used includes the number and seasonality of HFEs, daily flow
26 information, economic analysis, and fishery and vegetation management information that is
27 documented in other portions of this DEIS. Metric values are based on 20-year simulations of
28 Glen Canyon Dam releases under different hydrology and sediment conditions as determined for
29 the various LTEMP alternatives.

30

31 The economic analysis conducted by Gaston et al. (2015) quantified the net economic use
32 value (NEV) of recreation at Lakes Powell and Mead, and for three reaches of the Colorado
33 River: Glen Canyon, the Upper Grand Canyon, and the Lower Grand Canyon under the LTEMP
34 alternatives. The results of this analysis are presented in Section 4.14 and Appendix L.

35

36

37 **4.10.2 Summary of Impacts**

38

39 The impacts of LTEMP alternatives on visitor use and experience are summarized in
40 Table 4.10-1. Graphs showing the performance of the alternatives for each of the metrics are
41 shown in Figure 4.10-1. A more detailed analysis for each of the alternatives is presented in
42 Section 4.10.3.

43

44 Differences in the alternatives' effects on recreation tend to be mostly related to
45 differences in the frequency and characteristics of experimental flows, particularly HFEs and
46 TMFs, but are also related to differences in operations such as fluctuating flow effects during

1 **TABLE 4.10-1 Summary of Impacts of LTEMP Alternatives on Visitor Use and Experience**

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, declining camping area	Compared to Alternative A, comparable number of HFEs, higher fluctuations, and lowest catch rates; most navigability concerns; declining camping area similar to Alternative A	Compared to Alternative A, more HFEs, lower fluctuations, similar catch rates; fewer navigation concerns, increasing camping area	Similar to Alternative C, but with higher daily fluctuations	Similar to Alternative C, but with higher daily fluctuations	Compared to Alternative A and all other alternatives, most HFEs, steady flows, higher catch rates, but least large trout; very few navigability concerns, most lost Glen Canyon rafting trips, increasing camping area	Similar to Alternative F; greatest potential increase in camping area
Glen Canyon—Fishing							
Fish size, catch rate, and angler satisfaction with flow levels and fluctuations	No change from current conditions; intermediate catch rates and estimated 770 large trout (≥16 in.); high angler satisfaction with flow levels and daily fluctuations	Lowest angler catch rates, 13% more large trout; slightly lower angler satisfaction than Alternative A	Slightly higher catch rates than Alternative A; 3% fewer large trout (750); slightly lower angler satisfaction than Alternative A	Similar catch rates as Alternative A; 5% more large trout (810); slightly lower angler satisfaction than Alternative A	Similar catch rate as Alternative A; 8% more large trout (830); slightly lower angler satisfaction than Alternative A	Highest catch rates; 22% fewer large trout (600) and lower angler satisfaction than Alternative A due to high flows in peak angling months	Second highest catch rates; 9% fewer large trout (700) and slightly lower angler satisfaction than Alternative A

4-259

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Glen Canyon—Fishing (Cont.)</i>							
Navigability/safety	No change from current conditions; intermediate number of days when flows below 8,000 cfs could affect navigability; minimal safety concerns from up-ramp rates	Lowest navigability due to occasional flows below 8,000 cfs; slightly increased wading risk during tests of hydropower improvement flows	Somewhat higher navigability than Alternative A; minimal safety concerns from up-ramp rates	Same as Alternative A; minimal safety concerns from up-ramp rates	Somewhat lower navigability than Alternative A; minimal safety concerns from up-ramp rates	Somewhat higher navigability than Alternative A; minimal safety concerns, steady flows	Highest navigability, with few if any flows below 8,000 cfs; minimal safety concerns, steady flows
<i>Glen Canyon—Day Rafting/Recreation</i>							
Lost rafting visitor opportunities	No change from current conditions; estimated loss of 49 visitors/year out of a total of 50,000 due to HFEs (0.1%)	71 out of 50,000 fewer visitors/year due to HFEs	315 out of 50,000 fewer visitors/year due to HFEs	348 out of 50,000 fewer visitors/year due to HFEs	177 out of 50,000 fewer visitors/year due to HFEs	919 out of 50,000 fewer visitors/year because of large number of HFEs in peak rafting season	51 out of 50,000 fewer visitors/year due to HFEs
Camping and recreation facilities on old sediment terraces	No change from current conditions; lowest potential adverse impact on terraces; estimated 5.5 HFEs and no TMFs over the LTEMP period	Intermediate potential impact on terraces; estimated 7 HFEs, 3 TMFs, and 4 years with hydropower improvement flows	Intermediate potential impact on terraces; estimated 21 HFEs and 6 TMFs	Intermediate potential impact on terraces; estimated 21 HFEs and 4 TMFs	Intermediate potential impact on terraces; estimated 17 HFEs and 3 TMFs	Highest potential impact on terraces; estimated 38 HFEs, but no TMFs	Intermediate potential impact on terraces; estimated 24 HFEs and 11 TMFs

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Grand Canyon—Whitewater Boating							
Campsite area	No change from current conditions; lowest improvement of campsite area; would continue long-term decline since there are no HFEs after 2020; camping area index (CAI) = 0.14 out of 1	About the same as Alternative A; effects of 2 more HFEs offset by larger fluctuating flows; overall campsite loss is expected to continue, CAI = 0.15, an increase of 5% over Alternative A	Possible increase in campsite area; more HFEs than Alternative A, moderate fluctuations, and reduced fluctuation pre- and post-HFEs; CAI = 0.38, an increase of 170% over Alternative A	Similar to Alternative C; CAI = 0.36, an increase of 158% over Alternative A	Similar to Alternative C, but reduced fluctuation pre-HFEs only; CAI = 0.30, an increase of 118% over Alternative A	Similar to alternative C; most HFEs and no daily fluctuations, high sustained spring flows; CAI = 0.41, an increase of 191% over Alternative A	Highest improvement of campsite area; second most HFEs; steady, moderate flow; CAI = 0.45, an increase of 224% over Alternative A
Lakes Powell and Mead—Recreation Access Issues Based on Lake Elevation							
Lake Powell ^a	No change from current conditions; 21.8% of lake elevation simulated seasons indicate access issues (percent of seasons with access issues occurring in any month)	2.5% increase in lake elevation simulated seasons indicating access issues (22.3%)	Negligible (0.4%) increase in lake elevation simulated seasons indicating access issues (21.8%)	5.1% increase in lake elevation simulated seasons indicating access issues (22.9%)	5.1% increase in lake elevation simulated seasons indicating access issues (22.9%)	4.7% increase in lake elevation simulated seasons indicating access issues (22.8%)	4.7% increase in lake elevation simulated seasons indicating access issues (22.8%)
Lake Mead ^b	No change from current conditions; 25.5% of lake elevation simulated seasons indicate access issues (percent of seasons with access issues occurring in any month)	10.6% decrease in lake elevation simulated seasons indicating access issues (22.8%)	Negligible (0.3%) decrease in lake elevation simulated seasons indicating access issues (25.4%)	2.5% decrease in lake elevation simulated seasons indicating access issues (24.8%)	1.2% decrease in lake elevation simulated seasons indicating access issues (25.2%)	2.5% decrease in lake elevation simulated seasons indicating access issues (24.8%)	1.9% decrease in lake elevation simulated seasons indicating access issues (25.0%)

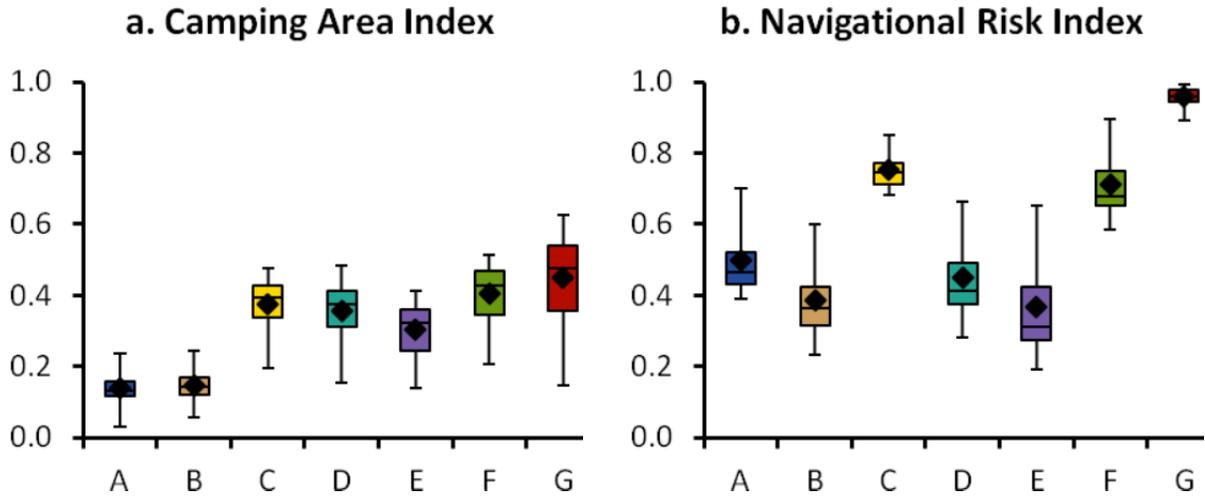
TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Tribal Recreation Program</i>							
Sediment impacts in lower Grand Canyon ^c	No change from current conditions; sand transported downstream at current rate until 2020, then reduced when HFEs cease	Slightly greater impacts than Alternative A due to slightly more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to most frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs
Impacts on park facilities at Pearce Ferry	No change from current conditions; facilities have been damaged in the past by HFEs; lowest of alternatives	Slightly greater impacts than Alternative A due to slightly more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to most frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs

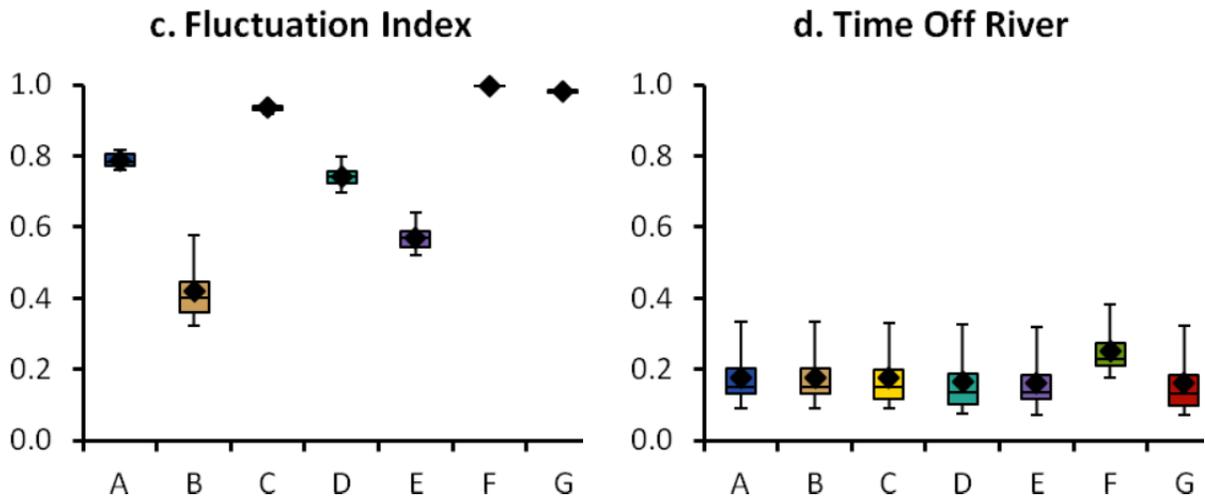
- ^a Percent of simulation seasons with at least 1 month with Lake Powell elevations equal to or below 3,580 ft AMSL, the level below which boat ramp access is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. See Appendix J.
- ^b Percent of simulation seasons with at least one month with Lake Mead elevations equal to or below 1,050 ft AMSL, the level below which marinas and boat ramp function is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. See Appendix J.
- ^c Relative sand mass transported downstream from Marble Canyon, RM 0 to 61 over the 20-year LTEMP period (Table 4.2-10). Transported sand could potentially have adverse effects on Hualapai recreational facilities in lower Grand Canyon.

4-262

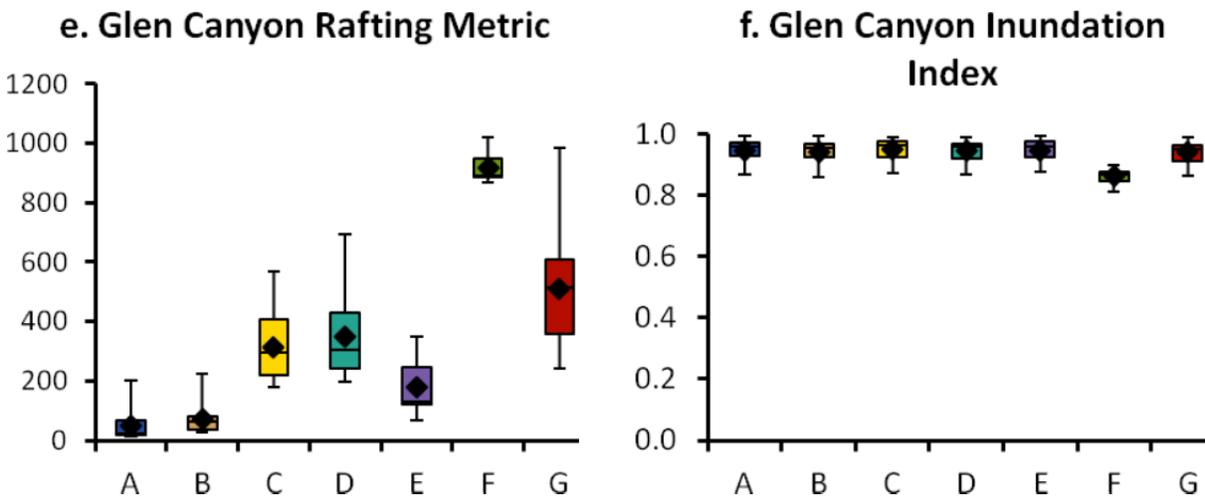
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6



7 **FIGURE 4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP**
 8 **Alternatives (Note that diamond = mean; horizontal line = median; lower extent of**
 9 **box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum;**
 10 **upper whisker = maximum.)**

1 high-demand seasons for hydropower. Effects are greater for actions that occur during peak
2 recreational use months, for example certain spring HFEs that may occur during the peak rafting
3 season. Some experimental flows and actions occur in only a few years; thus, for the majority of
4 time, the LTEMP alternatives' experimental flows cause little difference for recreation effects.
5 Differences in daily maximum and minimum flows under normal operations can, however,
6 distinguish between alternatives with respect to potential effects on recreation. Daily maximum
7 flows above 8,000 cfs increasingly reduce usable beach area, and would effectively submerge all
8 beach area at flows above 31,500 cfs (Section J.2.1.1). In addition, daily fluctuations resulting in
9 minimum flows below 8,000 cfs can affect river navigability and cause delays at rapids. Flow
10 fluctuations can also affect shoreline angling, and rafters who camp may be forced to move to
11 higher ground and to check boat moorings overnight. Such effects would not occur or would be
12 less prominent under alternatives with reduced fluctuation or steady flows (e.g., Alternatives A,
13 C, D, F, and G), while high steady flows under Alternative F in some spring and summer months
14 would reduce usable camping area. Lastly, not all effects are experienced by all recreational
15 users, and other effects are localized. For example, flow fluctuations may affect overnight
16 boaters who camp more than day-only boaters, while vegetation management and mechanical
17 trout removal are both localized actions that would affect recreation in only portions of the river
18 at any given time.

21 **4.10.2.1 Glen Canyon Fishing**

24 **Fluctuations and Water Levels**

26 Anglers in the Glen Canyon reach identified a preference for steady flows and flows
27 between 8,000 and 15,000 cfs (Bishop et al. 1987). Stewart et al.'s (2000) follow-up of the
28 Bishop et al. (1987) study after the implementation of MLFF flows in 1996 did not identify river
29 level fluctuations as an issue, and in 2011 an AZGFD creel study found that angler satisfaction in
30 the Glen Canyon reach was high (Anderson, M. 2012), indicating that the existing flow regime
31 was favorable for Glen Canyon anglers.

33 Steady flow Alternative F and Alternative G provide daily flows with no fluctuations;
34 Alternative G might be considered better for anglers because flows would be at preferred levels
35 throughout the year, whereas Alternative F has higher-than-preferred flows during some of the
36 most popular fishing months, April through June. The highest fluctuations of fluctuating flow
37 Alternatives C, A, D, E, and B (listed in order from lowest to highest within-day fluctuations)
38 may not occur during peak fishing months. Furthermore, because the daily fluctuations analyzed
39 in Bishop et al. (1987) were greater with respect to angling than those under the proposed
40 alternatives, little difference is expected in effects on angling between alternatives due to
41 fluctuations. Stewart et al. (2000) found that current fluctuations under MLFF were not identified
42 by anglers as an issue. The effects of flow and fluctuation levels on angler satisfaction under the
43 alternatives are quantified in economic terms in Section 4.14.2.1, which indicates that
44 Alternative A would have the highest angler use value by a small margin over all alternatives;
45 Alternative F would have the lowest due to high flows in peak fishing months.

1 The Glen Canyon Inundation metric was developed to identify the percentage of time
2 river flows were above certain elevations that affect boating, fishing, and shoreline access. The
3 metric is a measure of the suitability of flows between 3,000 and 31,500 cfs. Most alternatives
4 perform similarly with regard to this metric, with Alternative F having a slightly lower metric
5 value as illustrated in Figure 4.10-1. However, because all of the alternatives perform so
6 consistently on this metric, it will not be discussed further.

9 **Angling in the Glen Canyon Reach**

10
11 Anglers in the Glen Canyon reach are almost evenly split in their preference for catching
12 either large fish or for catching more fish (Anderson, M. 2012). Analysis described in more
13 detail in Section 4.4.2.2 concludes there will likely be differences among the alternatives both in
14 the percentages of larger fish (individuals exceeding 16 in. in length) in the population and in the
15 angler catch rate. Among the alternatives, the estimated number of large trout was generally
16 greatest under Alternative B and lowest under Alternatives F and G. Alternatives E, D, A, and C
17 in descending order are expected to produce intermediate numbers of large trout. The modeled
18 angler catch rates are greatest under Alternatives F and G because of their steadier flow regimes.
19 Based on this analysis, it is anticipated that recreational angling use in the Glen Canyon Reach
20 would be similar to the current situation under all alternatives and that angler satisfaction also
21 would likely remain high, but satisfaction for some alternatives would be based on the size of
22 fish, while that of others would be based on the number of fish.

25 **Navigability and Wading Safety in the Glen Canyon Reach**

26
27 The ability for boats to navigate freely within the Glen Canyon reach was an issue when
28 low flows of 1,000–3,000 cfs occurred prior to 1996. All alternatives now include a minimum
29 5,000 cfs flow between 7 PM and 7 AM, and 8,000 cfs from 7 AM to 7 PM (with the exception
30 of Alternative F, which has flows near or somewhat below 8,000 cfs all day during the summer,
31 fall, and winter). The Navigation Index (Figure 4.10-1) is based on the amount of time flows are
32 above 8,000 cfs. Alternatives B and E have lower Navigation Index values than Alternative A
33 due to more frequent low flows. Alternatives C, F, and G are higher than Alternative A, and
34 Alternative D is about the same as Alternative A.

35
36 Wading anglers are always at risk from swift water and from rapidly rising water levels,
37 and anglers are urged to exercise caution. Specifically, rapidly increasing flow is a safety
38 concern with respect to the ability of wading anglers to move toward shore. At least three
39 drownings in 12 years preceding the 1995 EIS possibly were related to river stage or stage
40 change (Reclamation 1995). Implementation of the MLFF protocol limiting up-ramp rates to
41 4,000 cfs/hr for all fluctuating-flow alternatives has reduced the potential safety concerns for
42 wading anglers. An up-ramp rate of 5,000 cfs/hr proposed under Alternative B during tests of
43 hydropower improvement flows could result in an adverse impact on safety of anglers due to
44 rapidly rising water levels. With respect to HFEs, Reclamation and NPS would coordinate to
45 ensure that safety measures are implemented during an HFE, including restricting access
46 immediately below Glen Canyon Dam, and providing public notice about the timing of an HFE.

1 Each of the affected NPS units—GCNRA, GCNP, and Lake Mead National Recreation Area
2 (LMNRA)—has clearly designated responsible parties, staffing needs, and actions that are
3 required to occur prior to and during an HFE.
4

6 **4.10.2.2 Glen Canyon Day Rafting**

7
8 The 15-mi Glen Canyon reach hosts a large number of day rafters who use the pontoon-
9 raft concession that departs from near Glen Canyon Dam and travels to Lees Ferry
10 (Section 3.11.1.2). Bishop et al. (1987) established that day rafting participants express no
11 preferences regarding either river flows or fluctuations. As a result, impacts on rafting use are
12 related only to the occurrence of HFEs, which result in lost visitor recreation opportunities and
13 lost revenue for the rafting concessioner. The variables influencing the level of impact are the
14 number of HFEs and the time of year in which they occur. Spring HFEs have a greater impact
15 than fall HFEs because visitor use is higher in the spring months. HFEs are scheduled only in
16 October, November, March, and April, with the exception of proactive spring HFEs (under
17 Alternatives C, D, and G), which can occur in April, May, or June.
18

19 Because of the high number of HFEs, Alternative F would have by far the greatest
20 adverse impact on day-use rafting with an anticipated mean annual loss of about 919 visitor
21 opportunities over the LTEMP period out of a typical annual total of 50,000 such trips expected
22 over the LTEMP period. Alternatives G, D, C, and E would have the next largest adverse
23 impacts with 512, 348, 315, and 177 mean annual lost visitor use opportunities, respectively.
24 Alternatives A and B would be similar in their impact and would result in 49 and 71 mean annual
25 lost visitor use opportunities, respectively (Figure 4.10-1).
26

28 **4.10.2.3 Glen Canyon Recreational Facilities**

29
30 Glen Canyon contains both high-elevation sediment terraces, which are remnants of
31 larger terraces that existed prior to construction of Glen Canyon Dam, and lower elevation
32 terraces, which are still affected by dam operations. Glen Canyon has six designated campsites
33 with fire pits and bathrooms along its 15-mi stretch. These recreational facilities are generally
34 located above the high-water level of normal dam operations; however, HFEs are the principal
35 flow actions that could affect these campsites through erosion of terraces combined with an
36 absence of sediment sources in the Glen Canyon reach for possible deposition and rebuilding of
37 terraces. Alternative F would have the largest adverse impact on these facilities from the
38 projected number of HFEs and annual spring floods (Table 4.2-1), followed by Alternatives G,
39 C, D, E, B and A, in decreasing order. In addition, higher fluctuation levels, including during
40 tests of hydropower improvement flows under Alternative B, could lead to increased campsite
41 erosion relative to the other alternatives.
42
43

1 **4.10.2.4 Whitewater Boating**
2

3 The availability, size, and quality of campsites in Grand Canyon is an important resource
4 for whitewater boaters. As discussed in Section 3.11-2, total campsite area has undergone a long-
5 term downward trend due to sandbar erosion and vegetation growth, having decreased by 56%
6 from 1998 to 2006 (Kaplinski et al. 2010). Generally, alternatives with more sediment-triggered
7 HFEs are expected to result in greater campsite area, although flow and fluctuation levels as well
8 as vegetation control will affect the maintenance of campsite area. Alternatives G and F show the
9 highest potential to create and maintain campsite area based on Camping Area Index values
10 (Figure 4.10-1). These are followed by Alternatives C, D, and E which have index values more
11 than two times greater than those of Alternatives A and B.
12

13 River flow levels and fluctuations are important for whitewater boaters
14 (Bishop et al. 1987; Hall and Shelby 2000; Stewart et al. 2000; Roberts and Bieri 2001). The
15 minimum daily flow levels of 5,000 cfs from 7 PM to 7 AM and 8,000 cfs from 7 AM to 7 PM
16 provided by most alternatives are considered only minimally adequate for Grand Canyon
17 boating. Transit times of morning flow increases to 8,000 cfs from 5,000 cfs overnight at the
18 dam to downstream locations may delay the arrival of 8,000 cfs or higher desired at more
19 challenging rapids. Such concerns would arise only in low-volume months, however, when
20 minimum flow limits would be applied. Flows on most days under the fluctuating flow
21 alternatives would exceed these limits. Steady flow Alternatives F and G could feature daily
22 flows of 5,000 cfs for extended periods of time; however, only four occurrences of 5,000 cfs
23 flows for a period of a month or more appeared in LTEMP 20-year hydrology simulations for
24 Alternative F, and there were none for Alternative G. Extended low flows of 5,000 cfs would
25 adversely affect navigability and trip management in GCNP because of a greater risk of boating
26 incidents. Conversely, the normal steady flows of Alternatives F and G would offer benefits to
27 river trip planning over the alternatives with fluctuating flows because river travel time and off-
28 river time is more predictable. Commercial and private whitewater trip leaders reported (Bishop
29 et. al. 1987) a preference for steady flows in the 20,000–26,000 cfs range. Alternative F
30 approaches these levels in April through June, and thus would have higher perceived value to
31 rafters than would Alternative G, which limits flows to near 12,000 cfs or less year round in
32 8.23-maf years.
33

34 The Navigation Index and the Fluctuation Index both address aspects of the impact of
35 fluctuations on whitewater boating (Figure 4.10-1). Both indices are designed to produce values
36 that increase in the direction of improved boating conditions. Thus, a higher Navigation Index
37 value indicates that an alternative presents relatively lower navigation risks due to low flows
38 (below 8,000 cfs), while higher Fluctuation Index values indicate that an alternative will have
39 fluctuations more often within a preferred range for whitewater boating (Bishop et al. 1987).
40 Alternatives G, F, and C have the highest values for both indices (indicating the best conditions),
41 while Alternatives B and E had the lowest index values (indicating the worst conditions).
42 Alternatives A and D have intermediate values for these two indices.
43

44 The Time Off-River Index values indicate there would not be much difference in time
45 available for off-river activities between the alternatives, likely due to similar mean annual flows

1 of between 10,000 and 15,000 cfs. Because the index does not provide a meaningful distinction
2 among the alternatives, it will only be referenced in special circumstances in Section 4.10.3.
3
4

5 **4.10.2.5 Lake Activities and Facilities**

6

7 Recreation on Lakes Powell and Mead can be affected by water levels dropping below
8 the level at which ramps and marinas can function. In the case of Lake Powell, the Castle Rock
9 cut is also a critical feature. Although the lowest boat ramp elevations on Lake Powell are not all
10 the same, 3,580 ft AMSL is representative of the level below which major access issues occur.
11 The frequency at which lake elevations would be above 3,580 ft AMSL at the end of the month
12 seasonally has been analyzed to determine whether there is any significant difference among the
13 alternatives. The same has been done for Lake Mead using an elevation of 1,050 ft AMSL, the
14 level to which the NPS has committed in order to keep marinas and launch ramps functional.
15

16 Simulations were performed of end of the month lake elevations by season (summer,
17 winter, or spring/fall) for the 20-year lake level simulations using 21 hydrology traces for both
18 lakes. For Lake Powell, with respect to the 3,580 ft AMSL reference level for boat access,
19 approximately 22% of all simulated seasons showed at least one month with end of the month
20 elevations at or below this level for all alternatives. There was very little difference among the
21 alternatives; all alternative means fall between 21.75% for Alternative A and 22.86% for
22 Alternative E. Such differences by alternative are likely due to small changes in elevation when
23 lake elevation is near the 3,580-ft reference level.
24

25 The results for Lake Mead simulations were similar to those for Lake Powell, with a
26 slightly greater range of results. Alternative B, with 22.78%, had the lowest percentage of
27 seasons with at least 1 month at or below the reference elevation, and Alternative A, with
28 25.48%, had the highest. Differences by alternative are likely due to small changes in elevation
29 when lake elevation is near the 1,050-ft reference level.
30

31 As discussed in Section 4.1.2.1, the elevations of Lake Powell and Lake Mead are more
32 affected by annual variation in inflow than by alternative. The dominating effect of hydrology
33 was also observed in the analysis of lake elevations with respect to lake access, with relatively
34 small effects attributable to differences in alternatives.
35
36

37 **4.10.2.6 Tribal Recreation Operations**

38

39 The Hualapai Tribe operates recreational facilities in the Lower Gorge of Grand Canyon
40 and their facilities and activities can be adversely affected by operation of the dam. The Hualapai
41 have expressed concern over dam operations they believe are increasing the amount of sediment
42 collecting in their operational area below Diamond Creek. Their primary operations are centered
43 in and around the Quartermaster area (RM 260). They have reported adverse impacts on their
44 commercial operations from river sediment, including turbidity effects on equipment, access to
45 their docks, and navigation in the river. They are also concerned over the steep and unstable
46 slopes previously inundated by Lake Mead that are now exposed due to lake levels retreating

1 from the previous high-water line. The issues associated with the steep and unstable shorelines in
2 the Lake Mead delta are related to the declining lake level, and will not be resolved until the
3 level of Lake Mead either regains its previous high levels or until the banks naturally stabilize
4 under new, lower lake levels. However, the number and duration of HFEs under the various
5 alternatives could have an effect on boat docks and other facilities operated by the Hualapai
6 Tribe.

7
8 It is expected that dam operations, HFEs, equalization flows, and other flow events will
9 continue to deliver sediment to the Lower Gorge in Grand Canyon and Lake Mead. Nearly all
10 sediment that enters the Grand Canyon below Lake Powell will eventually move downstream.
11 Higher flows, in general, do transport more sediment, and sediment transport will continue in the
12 free-flowing portions of the river below Diamond Creek.

13
14 Transport of sand downstream from sources in Marble Canyon (RM 0–RM 61) under
15 various LTEMP alternatives is discussed in Section 4.2. The least amount of sand would be
16 transported under Alternative A, primarily due to the cessation of the HFE protocol in 2020;
17 HFEs are the major source of sand transport under the alternatives. Sand transport would be
18 second lowest under Alternative D and greatest under Alternatives F and G. The estimated sand
19 transport out of Marble Canyon is as much as 230% greater under the highest alternative
20 (Alternative F) than under the lowest alternative (Alternative A). Although the percent difference
21 between Alternative F and Alternative A is large, this difference is small in comparison to the
22 overall system.

23
24 The amount of change in sand storage in Marble Canyon for Alternative A and
25 Alternative F, when compared to the estimated annual sand load from the Paria River
26 (approximately 830 ktons/yr), indicates that Alternative A will store 14% more sand from the
27 Paria River annually compared to Alternative F. A similar comparison can be made to the annual
28 sand flux that passes the USGS gage at RM 225, which is 35 river miles upstream of the
29 Hualapai recreational facilities and 164 river miles downstream of Marble Canyon. The increase
30 in sand that leaves Marble Canyon under Alternative F relative to Alternative A is 7% of the
31 annual sediment flux at RM 225 (Appendix E). There is very little difference between
32 alternatives in terms of sand transport to Hualapai recreational facilities and operations.

33 34 35 **4.10.2.7 Pearce Ferry**

36
37 As discussed in Section 4.9, park facilities at Pearce Ferry, managed by LMNRA, have
38 been damaged in the past by HFEs and are likely to be damaged by HFEs in the future. Effects
39 would vary among alternatives, and those with more frequent HFEs, particularly spring HFEs,
40 may have more effects. There would be temporary impacts in the months following HFEs to both
41 park operations and visitor access when there is damage until the takeout ramp is repaired.
42 Damage in April–June (following a spring HFE) would have more effects on visitors than in
43 November–January (following a fall HFE).

4.10.2.8 Park Operations and Management

As discussed in Section 3.10.4, potential effects on NPS staffing levels are related to recreation and resource concerns. For this analysis, staff levels were generally calculated as full-time equivalents, based upon known amounts of time currently dedicated to operational functions. To estimate the changes to staff levels that might be different among alternatives, an assumed relationship to a quantitative metric from modeling was used. For instance, if vegetation modeling indicated a 5% increase in nonnative invasive plants, it was assumed that there would be a 5% increase in the need for vegetation restoration work. Staff time for monitoring and maintenance of camping beaches and trails was estimated using the modeled Camping Area Index. Staff time related to special flows, such as HFEs or TMFs, was estimated based on the tracking of GCNRA and GCNP staff time for notification and coordination related to HFEs from 2011 to 2015. Flow patterns were looked at in terms of safety, and boating hazards and staff time for ranger patrols were analyzed, though this was looked at as trend information rather than quantitative contributions to the total as staff time for safety issues can vary greatly from year to year.

Another consideration that was evaluated was impacts on park facilities at Pearce Ferry, managed by LMNRA, as these facilities have been damaged in the past by HFEs and are likely to be damaged by HFEs in the future. Effects would vary between alternatives, as those with more frequent HFEs, particularly spring HFEs, may have more effects than those with fewer HFEs. There would be temporary impacts in the months following HFEs to both park operations and visitor access when there is damage, until the takeout ramp is repaired. Damage in April–June (following a spring HFE) would have more impact on visitors than damage in November–January (following a fall HFE).

Based on the analysis conducted, the maximum difference between action alternatives (B through G) and Alternative A was a 1.8 full-time equivalent decrease (Alternative D), and the maximum was an increase of 0.1 full-time equivalent (Alternative B). However, factors such as safety response and repairs at Pearce Ferry, which were considered but were not possible to quantify, did not vary in the same direction as the quantified effects. Therefore, the differences among alternatives may be less than indicated by the quantified effects. Based on this analysis, it was determined that the variation among alternatives for park staffing for recreation and resource concerns would be negligible.

4.10.3 Alternative-Specific Impacts

The following section provides descriptions of impacts that are expected to occur under each of the LTEMP alternatives.

4.10.3.1 Alternative A (No Action Alternative)

Under Alternative A, trout abundance, size, and catch rates are expected to vary within the ranges that have been observed under MLFF operations over the past 20 years. About

1 770 large trout (a number intermediate among the alternatives; large trout are defined as
2 individuals exceeding 16 in. in length) would be expected under Alternative A, as well as
3 intermediate levels of angler catch rates (Section 4.4.2.2). Therefore, under Alternative A overall
4 angler satisfaction is anticipated to remain the same as at present, with a consistent trend in the
5 fishery toward more, but smaller, fish. Alternative A is expected to result in the highest angler
6 satisfaction of all alternatives, by a small margin (Section 4.14.2.1).

7
8 Alternative A would have fewer HFEs that might disrupt angling than other alternatives,
9 and about 80% of the time daily fluctuations would remain in a range preferred by whitewater
10 boaters (Figure 4.10-1). Navigational boating risks due to flows below 8,000 cfs under
11 Alternative A, as reflected in the Navigation Index (Figure 4.10-1), would be about in the middle
12 of those for all alternatives. The current MLFF maximum up-ramp rate of 4,000 cfs/hour under
13 this alternative has been adopted for all DEIS alternatives and it is not anticipated that this ramp
14 rate would create angler safety issues. The down-ramp rate of 1,500 cfs is the same as the current
15 rate and also does not create issues for anglers.

16
17 Because this alternative only allows for HFEs until 2020 and has the fewest total number
18 of HFEs, Alternative A scores the best among alternatives in the Glen Canyon Rafting Metric,
19 with a projected mean annual loss of only 49 visitor rafting trips (Figure 4.10-1), compared to a
20 total mean annual visitor use of 50,000 visitors. This is a 0.01% reduction. In addition, the lower
21 number of HFEs would result in the lowest anticipated impact on the sediment terraces and the
22 recreational resources they support.

23
24 Having the lowest mean number of HFEs over the LTEMP period, Alternative A has
25 among the lowest potential for increasing campsite area of all alternatives (Figure 4.10-1). Based
26 on observed effects under the current MLFF operating regime, this alternative is expected to lead
27 to a continued loss of campsite area due to erosion and increased campsite crowding.

28
29 In addition to sediment-triggered spring and fall HFEs, several experimental elements are
30 featured in Alternative A, including mechanical removal of trout in the Little Colorado River
31 reach and testing TMFs. Mechanical trout removal activities are intensive activities that can last
32 many days and over a period of several months (Reclamation 2011a). Mechanical trout removal
33 activities would have a short-term impact to visitor experience from motorized use. Based on
34 modeling of trout numbers, there is a low probability that this activity will occur under
35 Alternative A during the LTEMP period. TMFs are intended to decrease trout abundance, which
36 might reduce angler catch rate, but could also result increasing the number of larger fish in the
37 fishery in the Glen Canyon reach. Under this alternative, TMFs would be tested but not
38 implemented.

39
40 In summary, there would be little change from current conditions under Alternative A.
41 Alternative A would have the fewest HFEs (ending in 2020), and moderate flow fluctuations.
42 Anglers would expect to see intermediate numbers of large trout and intermediate catch rates.
43 Few navigability concerns from low flows would occur. Concerns for angler safety from high
44 up-ramp rates would be low. Alternative A would have the fewest lost rafting trips resulting from
45 HFEs. Ongoing loss of camping area would continue, leading to increased crowding. There

1 would be very little interference with recreation from testing and implementing experimental
2 elements under the alternative.
3
4

5 **4.10.3.2 Alternative B**

6

7 Of all the alternatives, Alternative B has the lowest estimated number of rainbow trout
8 and trout emigrants in the trout fishery below Glen Canyon Dam, but it has the greatest estimated
9 number of large rainbow trout (>16 in.), about 870 fish. Hydropower improvement flows would
10 be expected to result in even lower trout abundance and emigration and an increase in the
11 numbers of large trout (Section 4.4.3.2). Angler catch rates would be the lowest of all
12 alternatives because of the relatively low number of trout under this alternative. Alternative B is
13 expected to have angler satisfaction similar to that under Alternative A and all other alternatives,
14 except Alternative F, which would have somewhat reduced satisfaction due to high flows in peak
15 fishing months (Section 4.14.2.1).
16

17 High daily fluctuations and sharp down-ramp rates as high as 4,000 cfs/hour, compared
18 to a maximum of 1,500 cfs/hour under Alternative A, result in relatively low navigability due to
19 more frequent flows below 8,000 cfs (Figure 4.10-1).
20

21 Alternative B is expected to have slightly more HFEs than Alternative A; there would be
22 a mean of 7.5 versus 5.5 during the 20-year LTEMP period (Table 4.2-1), resulting in an
23 anticipated mean loss of 71 annual Glen Canyon day-rafting opportunities for this alternative
24 (Figure 4.10-1). This represents a negligible impact in terms of fewer visitors/year in comparison
25 to Alternative A. The estimated annual visitor use total is about 50,000.
26

27 Under Alternative B, due to the slightly higher number of HFEs during the LTEMP
28 period, there is a slightly increased likelihood of additional impacts on sediment terraces in the
29 Glen Canyon reach that support recreation facilities and campsites.
30

31 Alternative B is expected to result in slightly more camping area than Alternative A
32 (Figure 4.10-1) due to a higher number of HFEs, but there would be a continued declining trend
33 in campsite area due to high flow fluctuations. Total number of campsites and campsite area
34 would continue to decrease under Alternative B, potentially increasing competition and crowding
35 at campsites. Usable campsite area would be further restricted by high daily fluctuations, which
36 limit campsites to areas above the highest water level.
37

38 As stated above, daily fluctuations under Alternative B would be greater than under any
39 other alternative. In addition, the down ramp rate is 2 to 2.6 times higher than under
40 Alternative A, which could lead to boats being stranded in both GCNRA and GCNP resulting in
41 a minor adverse impact on boating associated with the level of river fluctuations.
42

43 In addition to sediment-triggered spring and fall HFEs, several experimental elements are
44 featured in Alternative B, including mechanical removal of trout in the Little Colorado River
45 reach, testing and implementing TMFs, and testing hydropower improvement flows in 4 years
46 during the LTEMP period when annual volume is ≤ 8.23 maf (Section 2.3.2).

1 The impacts of mechanical trout removal activities would be similar to those described
2 under Alternative A; however, based on modeling of trout numbers there is a low probability that
3 this activity will be triggered under Alternative B during the LTEMP period.
4

5 TMFs are expected to be triggered relatively infrequently under this alternative (mean of
6 three TMFs triggered over the 20-year LTEMP period); therefore the overall impact of TMFs on
7 recreation is expected to be minimal. TMFs are intended to decrease trout abundance in the
8 fishery in the Glen Canyon reach, which could result in a reduced angler catch rate but could also
9 increase the number of larger fish.
10

11 Tests of hydropower improvement flows in 4 years when annual volume is ≤ 8.23 maf
12 would more closely resemble the operations at Glen Canyon Dam prior to the early 1990s, and
13 would produce daily fluctuations up 20,000 cfs (5,000 cfs nighttime to 25,000 cfs daytime). The
14 daily minimum flow would be 5,000 cfs and the up- and down-ramp rates would each be
15 5,000 cfs/hr. High ramp rates, when combined with the overall level of fluctuations under
16 Alternative B, would create additional difficulties in navigating rapids and managing boats tied
17 to shore. In the 1995 EIS (Reclamation 1995), rapidly increasing flow was identified as a safety
18 concern for wading fishermen with respect to their ability to move toward shore. This pattern of
19 river fluctuations and high daytime flows would also adversely affect fishing and usable
20 campsite area.
21

22 In summary, Alternative B would have the second fewest HFEs and the greatest flow
23 fluctuations; the former would result in relatively few days that would disrupt angling and
24 boating from river closings, similar to Alternative A, and the latter would result in reduced
25 whitewater boater satisfaction due to high daily fluctuations compared to Alternative A. The
26 number of large trout would be highest of all alternatives, but catch rates lowest. Navigability
27 and boat stranding concerns would be the greatest of all alternatives due to high fluctuations and
28 high down-ramp rates, but relatively low overall. Few lost rafting trips due to HFEs would occur,
29 similar in number to Alternative A. Camping area is expected to continue to decrease due to
30 erosion, similar to Alternative A. Interference with recreation from testing and implementing
31 experimental elements would be low and similar to that under Alternative A, with the exception
32 of hydropower improvement flows, which would produce greater impacts than under
33 Alternative A.
34
35

36 **4.10.3.3 Alternative C** 37

38 Under Alternative C, about 750 large trout are predicted to be present below Glen
39 Canyon Dam, similar to the number under Alternative A (770); angler catch rates would be
40 similar to those under Alternatives A, D, and E, more than under Alternative B and less than
41 under Alternatives F and G. Angler satisfaction under this alternative is estimated to be slightly
42 lower than those under Alternative A and similar to those under all other alternatives except
43 Alternative F, which would have the lowest expected satisfaction due to high flows during peak
44 fishing season (Section 4.14.2.1).
45

1 Within the 20-year LTEMP period, Alternative C is expected to have more HFEs (21)
2 than Alternative A that would disrupt angling and boating. Conversely, a low frequency of flows
3 below 8,000 cfs results in good navigation (Figure 4.10-1), exceeded only by Alternative G. The
4 down-ramp rate is 1.7 times that under Alternative A, but it is not expected to create an issue for
5 anglers.

6
7 The more frequent HFEs under this alternative would result in an estimated 315 lost day-
8 rafting visitor opportunities (Figure 4.10-1) as compared to a loss of 49 such opportunities under
9 Alternative A. In addition, under Alternative C, the larger mean number of HFEs is expected to
10 result in erosion of sediment terraces from wetting and undercutting in the Glen Canyon reach
11 that support recreation facilities and campsites.

12
13 Because of the relatively high number of HFEs and moderate fluctuations under
14 Alternative C, it has a relatively high probability of producing an increase in campsite area
15 relative to Alternatives A, B, and E (Figure 4.10-1) resulting in a beneficial effect to the visitor
16 experience. HFEs could adversely affect Hualapai recreational facilities in the western Grand
17 Canyon.

18
19 In addition to sediment-triggered spring and fall HFEs, there are several experimental
20 elements featured in Alternative C, including proactive spring HFEs, extended duration HFEs,
21 mechanical removal of trout in the Little Colorado River reach, testing and implementing TMFs,
22 and testing and implementing low summer flows.

23
24 Implementing proactive spring HFEs and longer duration HFEs would disrupt day-rafting
25 operations and cause a small increase in lost visitor opportunities and loss of concessioner
26 revenue, as well as disruption of visitor trip schedules. Proactive spring HFEs have potential to
27 conserve sediment and might slightly increase or help maintain camping area over the long term.
28 Mechanical trout removal activities would be triggered infrequently and would limit visitor
29 access to portions of the river for several days over several months when they occur.

30
31 TMFs are intended to decrease trout abundance, which might reduce angler catch rate,
32 but could also result in an increased number of larger fish in the Glen Canyon reach. TMFs are
33 expected to be triggered six times during the 20-year LTEMP period under Alternative C,
34 compared to no TMFs under Alternative A (Table 4.8-2).

35
36 The impacts of testing low summer flows would vary depending on the level of flows and
37 the number of years they are employed. Flows of 8,000 cfs would result in a short-term increase
38 in available camping area, a decrease in rafter time off river for exploration, and potentially more
39 difficult navigation.

40
41 In summary, Alternative C would have almost 4 times the number of HFEs as
42 Alternative A, but lower daily fluctuation levels. The number of larger trout and trout catch rates
43 would be similar to Alternative A. Few navigation concerns would exist, similar to
44 Alternative A. However, the number of lost rafting trips due to HFEs would be about 6 times that
45 of Alternative A, but still a small fraction of total rafting trips. Camping area is expected to
46 increase somewhat due to the effects of HFEs, while continued reduction is expected under

1 Alternative A. Interference with recreation from testing and implementing experimental elements
2 would be greater than under Alternative A.
3
4

5 **4.10.3.4 Alternative D (Preferred Alternative)** 6

7 Under Alternative D, an estimated 810 large trout are predicted to be present in the trout
8 fishery below Glen Canyon Dam, with angler catch rates similar to those under Alternatives A,
9 C, and E; this would be more than under Alternative B, and less than under Alternatives F and G.
10 Angler satisfaction under Alternative D would be similar to that under Alternative A and all
11 other alternatives except Alternative F, which would have somewhat reduced angler satisfaction
12 due to high flows during peak fishing season.
13

14 With an estimated 21 HFEs within the 20-year LTEMP period (Table 4.2-1),
15 Alternative D would disrupt angling and boating more often than would Alternative A, with a
16 mean of 5.5 HFEs. Daily flow fluctuations and daily minimum flows that may affect navigability
17 under Alternative D are similar to those under Alternative A (Figure 4.10-1).
18

19 Restricted boating during HFEs under this alternative would result in an estimated
20 348 lost day-rafting visitor opportunities (Figure 4.10-1). This is an increase of about 290 over
21 that under Alternative A. In addition, more frequent HFEs under Alternative D compared to
22 Alternative A are expected to result in relatively greater erosion of sediment terraces due to
23 wetting and undercutting the Glen Canyon reach that supports recreation facilities and campsites.
24

25 Because of the relatively high number of HFEs and moderate fluctuations, Alternative D
26 is expected to benefit campsite area—as reflected in the Camping Area Index—more than
27 Alternatives A, B, and E, and less than Alternatives C, F, and G (Figure 4.10-1). However, the
28 relatively high number of HFEs could adversely affect Hualapai recreational facilities in the
29 western Grand Canyon.
30

31 In addition to sediment-triggered spring and fall HFEs, several experimental elements are
32 featured in Alternative D that could produce short-term effects on recreation; these include
33 proactive spring HFEs, extended duration HFEs, mechanical removal of trout in the Little
34 Colorado River reach, testing and implementing TMFs, and testing and implementing sustained
35 low flows to improve benthic invertebrate production and low summer flows to improve
36 recruitment of humpback chub. Although the direct effects on recreation of these experimental
37 elements generally occurs from disruption of day-rafting over the duration of the experiment,
38 long-term indirect benefits for recreation may accrue from the adoption of successful treatments,
39 including potentially improved campsite area and improved aquatic food base that supports the
40 trout fishery.
41

42 Implementing a proactive spring HFE and longer duration HFEs would disrupt day-
43 rafting operations, cause a temporary increase in lost visitor opportunities, disrupt visitor trip
44 schedules, and result in a loss of concessioner revenue. Proactive spring HFEs have potential to
45 conserve sediment and slightly increase or help maintain camping area over the long term.

1 Mechanical trout removal activities, although triggered infrequently, might limit visitor access to
2 portions of the river for several days over several months when they occur.

3
4 TMFs are intended to decrease trout abundance, which might reduce angler catch rate;
5 however, it could also result in an increased number of larger fish in the fishery in the Glen
6 Canyon reach. Such effects would be expected to be fairly short term due to the dynamic nature
7 of the fishery. TMFs are expected to be triggered in 4 years over the 20-year LTEMP period,
8 compared to no TMFs under Alternative A (Table 4.8-2).

9
10 Low summer flows would be tested only twice and only in the second 10 years of the
11 20-year LTEMP period. Flows of 8,000 cfs or less would result in a short-term increase in
12 available camping area, a decrease in rafter time off river for exploration, potentially more
13 difficult navigation, and potential loss of business by commercial rafters and fishing guides
14 because of low flows. Testing sustained low flows to improve benthic invertebrate production
15 would similarly involve steady flows on every weekend from May through August (34 days
16 total). The flow on weekends would be held to the minimum flow for that month. Testing would
17 not be conducted in the first 2 years of LTEMP. Effects on recreation would be similar to those
18 for low summer flows.

19
20 In summary, Alternative D would have almost 4 times the number of HFEs as
21 Alternative A and similar daily fluctuation levels. The number of larger trout and trout catch
22 rates would be similar to Alternative A. Few navigation concerns would exist, similar to
23 Alternative A. However, the number of lost rafting trips due to HFEs would be about seven times
24 that of Alternative A. Camping area is expected to increase somewhat due to the effects of HFEs,
25 compared to an expected reduction under Alternative A. Interference with recreation from testing
26 and implementing experimental elements would be greater than under Alternative A.

27 28 29 **4.10.3.5 Alternative E**

30
31 Alternative E is expected to result in an estimated number of rainbow trout and trout
32 emigrants near the low end of alternatives and similar to Alternative A, with the second-highest
33 expected number of large rainbow trout (about 830 fish) in the trout fishery below Glen Canyon
34 Dam after Alternative B (Section 4.4.3.3). Angler catch rates similar to those under
35 Alternative A would be expected. Angler satisfaction under Alternative E is projected to be
36 similar to that under Alternative A and under all other alternatives except Alternative F, which
37 has somewhat reduced expected satisfaction due to high flows during peak fishing season.

38
39 Under Alternative E, there would be an estimated 17 HFEs that would disrupt angling
40 and boating, an intermediate number among the alternatives. The down-ramp rate of this
41 alternative is 1.7 times that of Alternative A, but it is not expected to create an issue for anglers.
42 The Fluctuation Index (Figure 4.10-1) indicates that whitewater rafting satisfaction would be
43 lower than under all other alternatives except Alternative B, while the Navigation Index
44 (Figure 4.10-1) is lower than all other alternatives except Alternative B.

1 The more frequent HFEs under this alternative would result in a small impact and would
2 result in an estimated 177 lost day-rafting visitor opportunities (Figure 4.10-1), an increase of
3 146 over Alternative A. In addition, under Alternative E, the larger mean number of HFEs is
4 expected to result in an increase in adverse impacts on sediment terraces in the Glen Canyon
5 reach that supports recreation facilities and campsites, compared to Alternative A.
6

7 Because of the relatively high number of HFEs under Alternative E, this alternative is
8 expected to benefit campsite area (Figure 4.10-1) more than Alternatives A and B, but somewhat
9 less than Alternatives C, D, F and G. However, HFEs could adversely affect Hualapai
10 recreational facilities in the western Grand Canyon.
11

12 In addition to sediment-triggered spring and fall HFEs, several experimental elements are
13 featured in Alternative E, including mechanical removal of trout in the Little Colorado Reach,
14 testing and implementing TMFs, and testing low summer flows in the second 10 years of the
15 LTEMP period.
16

17 The impacts of mechanical removal of trout in the Little Colorado reach would be similar
18 to those described under Alternative A. Overall, there is a low probability that this action would
19 be triggered during the LTEMP period based on the expected number of trout in the Little
20 Colorado River reach. The impacts of TMFs, estimated to occur in 3 of 20 LTEMP years, would
21 be the same as discussed for Alternative B.
22

23 The impacts of testing low summer flows would be the same as discussed under
24 Alternative C. When they are tested, summer flows of 8,000 cfs would result in a short-term
25 increase in available camping area, a decrease in rafter time off river for exploration, potentially
26 more difficult navigation, and potential loss of business by fishing guides due to angler
27 perception of less-desirable fishing conditions.
28

29 In summary, Alternative E would have 3 times as many HFEs as Alternative A and
30 similar daily fluctuations. The number of large trout would be higher than under Alternative A,
31 while catch rates would be similar. Few navigation concerns would exist, but slightly more than
32 under Alternative A. The number of lost rafting trips due to HFEs would be 3 to 4 times that of
33 Alternative A, but still a small fraction of total rafting trips. Camping area is expected to increase
34 somewhat due to the effects of HFEs, compared to an expected reduction under Alternative A.
35 Interference with recreation from testing and implementing experimental elements would be
36 greater than under Alternative A.
37
38

39 **4.10.3.6 Alternative F**

40
41 The steady daily flows of Alternative F are expected to result in higher numbers of trout
42 and increased angler catch rates, but the lowest number of large trout of all alternatives
43 (600 fish). In addition, this alternative does not include any trout management actions
44 (i.e., mechanical removal and TMFs). Overall angler satisfaction under Alternative F, however,
45 is anticipated to be lowest of all alternatives due to high flows during peak fishing season
46 (Section 4.14.2.1). In addition, Alternative F has the highest number of HFEs (39) of all

1 alternatives, including a 1-day HFE in early May in all years without a sediment-triggered spring
2 HFE and an annual 7-day 25,000-cfs flow at the end of June that would occur during prime
3 fishing months, which would also adversely impact fishing.
4

5 With most daily flows near or above 8,000 cfs, navigability is expected to be relatively
6 high (Figure 4.10-1). Thus, conditions are anticipated to be satisfactory for boaters most of the
7 time, except during HFEs. An anticipated mean annual loss of 919 day-use rafting opportunities
8 due to HFEs (Figure 4.10-1) is the largest such loss of any alternative and about 20 times that of
9 Alternative A. In addition, the large number of HFEs in Alternative F would tend to increase
10 erosion of sediment terraces in the Glen Canyon reach that support recreation facilities and
11 campsites.
12

13 With a high number of HFEs and steady monthly flows, Alternative F has a high
14 likelihood of benefitting campsite area (Figure 4.10-1). Steady daily flows would result in
15 predictable availability of campsites. However, usable campsite area would be reduced
16 somewhat compared to Alternative G, due to high seasonal flows in March through June under
17 Alternative F. Overall, the alternative would benefit total campsite area. However, the relatively
18 high number of HFEs could adversely affect Hualapai recreational facilities in the western Grand
19 Canyon.
20

21 There are no experimental elements in this alternative, other than HFEs, that could affect
22 recreation.
23

24 In summary, Alternative F would have the greatest number of HFEs of all alternatives.
25 The fewest large trout are expected under this alternative, but highest catch rates. Very few
26 navigability concerns would exist from low flows and no safety or convenience concerns from
27 daily fluctuations. However, the most lost rafting trips due to HFEs would occur, about 20 times
28 the number under Alternative A. Alternative F is expected to be the second most beneficial of all
29 alternatives with respect to increasing camping area due to the effects of HFEs and reduced
30 erosion. It would have no interference with recreation from testing and implementing
31 experimental actions beyond those related to HFEs.
32
33

34 **4.10.3.7 Alternative G** 35

36 With regard to Glen Canyon angling, Alternative G would have the second-lowest
37 number of large trout (700 fish), but trout abundance and angler catch rates would be high.
38 Angler satisfaction under this alternative is expected to be slightly less than that under
39 Alternative A and similar to that under all other alternatives, except Alternative F, which is
40 expected to result in somewhat reduced angler satisfaction due to high flows during peak fishing
41 season (Section 4.14.2.1).
42

43 The steady monthly flows under Alternative G would be consistently within the preferred
44 range for anglers, near 10,000 cfs, and few daily flows below 8,000 cfs reflect high navigability
45 under Alternative G (Figure 4.10-1).
46

1 The relatively high number of HFEs under this alternative would result in an anticipated
2 annual loss of 512 visitor rafting opportunities over the LTEMP period (Figure 4.10-1); more
3 than 10 times larger than under Alternative A. The number of HFEs would result in a higher
4 tendency to erode sediment terraces that support recreation facilities and campsites compared to
5 all alternatives but Alternative F.

6
7 Because of the high number of HFEs under Alternative G, and its steady monthly and
8 daily flows, it has the highest likelihood of any alternative of benefiting total campsite area
9 (Figure 4.10-1). Because Alternative F has lower flows in summer and fall months, that
10 alternative may result in greater useable camping area during those months than under
11 Alternative G. Thus, the two alternatives may be considered equals with respect to campsite
12 crowding.

13
14 In addition to sediment-triggered spring and fall HFEs, several experimental elements are
15 featured in Alternative G, including proactive spring HFEs in April, May, or June; extended-
16 duration HFEs; mechanical removal of trout in the Little Colorado Reach; and testing and
17 implementation of TMFs.

18
19 Implementing a proactive spring HFE and extended-duration HFEs would disrupt day-
20 rafting operations, cause a small temporary increase in lost visitor opportunities, disrupt visitor
21 trip schedules, and result in a loss of concessioner revenue. Proactive spring HFEs have the
22 potential to conserve sediment and slightly increase or help maintain camping area over the long
23 term. Relatively frequent HFEs could impact Hualapai recreational facilities in the western
24 Grand Canyon.

25
26 The impacts of mechanical trout removal activities would be similar to those described
27 under Alternative A. Based on the expected number of trout in the Little Colorado River reach,
28 Alternative G has an estimated three such removals, the greatest number triggered during the
29 LTEMP period of all alternatives (Table 4.8-2).

30
31 The impacts of testing and implementing TMFs would be similar to those described for
32 Alternative B. Based on the anticipated higher trout recruitment levels, Alternative G is expected
33 trigger TMFs in 11 of 20 LTEMP years (Table 4.8-2), the highest number of all alternatives.

34
35 In summary, Alternative G would have fewer large trout than Alternative A, but catch
36 rates would be higher. Very few navigability concerns would exist from low flows and no safety
37 or convenience concerns from daily fluctuations. There would be about 10 times more lost
38 rafting trips due to HFEs than under Alternative A. Alternative G is expected to be the most
39 beneficial of all alternatives with respect to increasing camping area due to the effects of HFEs
40 and reduced erosion. Interference with recreation from testing and implementing experimental
41 elements would be greater than under Alternative A.

1 **4.11 WILDERNESS**
2

3 This section presents the potential
4 impacts on wilderness and visitor wilderness
5 experience. Background information on the
6 wilderness qualities evaluated in this analysis
7 appears in Section 3.15. There are also references
8 to Section 4.10, Visitor Use and Experience.
9

10
11 **4.11.1 Analysis Methods**
12

13 The analysis of impacts on wilderness and
14 visitor wilderness experience downstream of
15 Glen Canyon Dam was based on an assessment
16 of alternative-specific differences in four
17 indicators of the quality of visitor wilderness
18 experience: opportunities for solitude at campsites and on the river; preservation of natural
19 conditions as reflected by naturalness of flow; opportunities for experiencing wilderness as
20 indicated by the amount of time rafters have for exploration; and visual and noise disturbances.
21 These indicators are evaluated qualitatively and comparatively as they relate to the differing
22 properties or features of the seven alternatives.
23

24 The effects of the alternatives on campsite crowding and its effect on visitor wilderness
25 experience was evaluated through consideration of the tendency of flow patterns and
26 experimental flows (mainly HFEs) under the various alternatives to build beaches and thus
27 potentially increase campsite area. The likelihood of rafters encountering other groups at rapids
28 was evaluated based on the expected frequency of daily flows less than 8,000 cfs, a flow level
29 associated with rafting delays at rapids as rafters scout conditions or wait for higher flows. Flows
30 of 8,000–9,000 cfs have been identified by commercial guides as the minimum level necessary to
31 safely run the river with passengers (Bishop et al. 1987; Stewart et al. 2000).
32

33 The naturalness of flows was evaluated by determining the magnitude of daily flow
34 fluctuations under alternatives as compared to fluctuation levels perceived to be less natural,
35 generally greater than 10,000 cfs as identified by Bishop et al. (1987). Stewart et al. (2000) found
36 that daily fluctuations of 5,000–8,000 cfs under MLFF were not an issue for most recreational
37 use, but they did not address fluctuations above 10,000 cfs. Opportunities for rafters to explore
38 attraction sites or enjoy personal time at camp were evaluated by determining the effects of flow
39 on river travel duration and the amount of off-river time available each day. Finally, the effects
40 of noise and visual disturbance of wilderness values was evaluated by considering the number of
41 HFEs, TMFs, trout removals, and the relative number of administrative trips expected under the
42 alternatives.
43

44 The metrics described in Section 4.10 were used as input to the evaluation of effects on
45 wilderness experience. The potential for beach building used the Camping Area Index to
46 evaluate the effects of campsite availability and size on potential crowding and opportunities for

Issue: How do the alternatives affect wilderness and visitor wilderness experience?

Impact Indicators:

- Opportunities for solitude at campsites and on the river
- Preservation of natural conditions as reflected by naturalness of flow
- Rafters' time available for onshore exploration
- Visual and noise disturbances from administrative uses

1 solitude (Figure 4.10-1a); the Navigation Risk Index was used to evaluate potential crowding at
2 rapids (Figure 4.10-1d); the Fluctuation Index was used to evaluate the naturalness of
3 flows(Figure 4.10-1c); and the Time-Off-River Index was used to evaluate the opportunity for
4 onshore exploration (Figure 4.10-1b). The effects of HFEs, TMFs, trout removal, and other
5 experimental actions were evaluated from estimates of the expected frequency of such actions
6 for the alternatives. Using these metrics and supporting information, it was possible to rank the
7 alternatives with respect to their relative effects on associated wilderness values. The details of
8 the methodology used to produce metric values and detailed results are presented in Appendix J.

11 **4.11.2 Summary of Impacts**

13 In Section 3.15, wilderness character is described as having four qualities: untrammelled,
14 natural, undeveloped, and providing for outstanding opportunities for solitude or a primitive and
15 unconfined form of recreation. In describing the wilderness values and visitor experiences within
16 GCNP that are to be preserved and protected, GCNP's General Management Plan states that
17 "Visitors traveling through the canyon on the Colorado River should have the opportunity for a
18 variety of personal outdoor experiences, ranging from solitary to social. Visitors should be able
19 to continue to experience the river corridor with as little influence from the modern world as
20 possible. The river experience should help visitors to intimately relate to the majesty of the
21 canyon" (NPS 1995).

23 Dam operations and management activities considered under LTEMP alternatives can
24 affect these wilderness values and the quality of the wilderness river experience for river visitors.
25 As dam operations affect beach retention or building, operations under the alternatives can affect
26 campsite crowding and solitude. Similarly, low daytime flows less than 8,000 cfs can increase
27 crowding at rapids. Although these are conceivable effects on wilderness experience and have
28 been modeled for the alternatives, such effects would detract only slightly from an overall
29 wilderness experience in the study area, and differences in the effects of alternatives would be
30 difficult to discern.

32 Wilderness experience may also be affected by high daily fluctuations that appear to be
33 greater than what would occur naturally. Fluctuations in excess of 10,000 cfs have been
34 identified as creating less natural conditions on the river (Bishop et al. 1987). TMFs and HFEs
35 would also present less natural conditions to visitors. However, daily fluctuations under MLFF
36 and the proposed alternatives are generally constrained to near or less than 10,000 cfs and thus
37 would have at most a small effect on perceptions of naturalness, differences in which would be
38 difficult to discern among fluctuating flow alternatives; the steady flow Alternatives F and G
39 would have no such effects.

41 Overall flow level can also affect the wilderness experience through effects on the
42 duration of rafting trips and thus the time available for onshore exploration. However, because
43 there is little difference among the alternatives in time off river (Figure 4.10-1b), this measure is
44 not discussed further in this analysis.

1 Finally, resource management actions, (i.e., administrative actions) including
2 experimental vegetation restoration under all alternatives but Alternative A; mechanical removal
3 of trout, which is allowed under some alternatives; and other experimental work and
4 administrative trips common to all alternatives can affect visitor experience by increasing
5 encounter rates, placement and use of equipment, and noise from motorized equipment. Such
6 effects would be infrequent and short term and would affect relatively few visitors. Vegetation
7 actions, even though they would conform to minimum tool use requirements, may have short-
8 term negative effects during disturbance but long-term positive effects on wilderness by
9 returning native vegetation and hence wilderness character. Effects on wilderness experience of
10 the LTEMP alternatives are summarized and compared in Table 4.11-1 and analyzed in the
11 discussions that follow.

12
13 Campsite crowding has been reduced since the implementation in 2006 of the CRMP
14 (NPS 2005a), but campsite area and campsite size was decreasing (Kaplinski et al. 2010) prior to
15 adoption of the HFE protocol in 2011 (Reclamation 2011b). Alternatives that do not reverse the
16 trend of loss in campsite area eventually would have an adverse effect on wilderness qualities
17 because of increases in crowding at remaining campsites. On the basis of the number of HFEs
18 anticipated under each of the alternatives (Section 4.3), Alternatives F and G are expected to
19 result in the greatest benefit to visitor wilderness experience with respect to opportunity for
20 solitude, because of a greater likelihood of increasing and retaining campsite area
21 (Section 4.10.2). Alternatives C, D, and E rank just below Alternatives F and G, while
22 Alternatives A and B rank lowest with regard to camping area as a consequence of having the
23 fewest HFEs. Under Alternative A (the No Action Alternative), HFEs would not be implemented
24 after the HFE protocol expired in 2020.

25
26 On the basis of allowable within-day fluctuation, Alternatives B and E would have more
27 frequent occurrences of very low flows (about 60% of days), including in the periods of peak
28 recreational use, and therefore would tend to result in more crowding at rapids as rafters stop to
29 scout rapids or wait for flows to rise. Alternatives D and A would be similar to each other and
30 comparable to current conditions (about 50% of days with low flows), while Alternatives F, C,
31 and G would have the fewest days with low flows (about 5% to 30% of days), and would result
32 in the lowest chances of encountering other groups. Although these comparisons are easily made
33 on the basis of the flow patterns of the alternatives, the actual effects on crowding at rapids may
34 be small overall, and small differences noted between alternatives may not be significant.

35
36 Daily flow fluctuations in excess of 10,000 cfs have been identified as creating less
37 natural conditions on the river. The effect of such flow fluctuations on wilderness experience
38 was evaluated using the fluctuation index (Section J.2.3 in Appendix J) developed from
39 maximum “tolerable” fluctuations preferred by whitewater rafters (Table 3.10-2), which are
40 generally less than 10,000 cfs and depend on overall flow level (Bishop et al. 1987). The
41 fluctuation index is presented in Section 4.10, where it is used to evaluate effects of fluctuations
42 on whitewater rafting. It is used here as a surrogate for effects on perceived natural conditions in
43 the Grand Canyon. Alternatives F and G, which employ steady flows, have fluctuation index
44 values near 1.0, indicating no within-day fluctuations. Fluctuating flow Alternatives A, C, and D
45 would be similar to each other, with most fluctuations within the preferred range; they would
46 have fluctuation index values of 0.79, 0.93, and 0.74, respectively. Alternatives B and E would

1 **TABLE 4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience**

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Declining camping area following cessation of HFEs would reduce opportunity for solitude; intermediate effects on crowding at rapids and levels of fluctuations; lowest disturbance from experimental actions.	Relative 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.	Relative to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, greater disturbance from non-flow actions.	Relative to Alternative A, reversal of camping area decline, similar level of fluctuations, greater disturbance from non-flow actions.	Relative to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, greater disturbance from non-flow actions.	Relative 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.	Relative to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Campsite crowding as indicated by the camping area index (CAI)	No change from current conditions; lack of HFEs after 2020 would lead to continued declining size and number of campsites and could result in further crowding and adverse effects on solitude; CAI = 0.14 out of 1.	Relatively few HFEs and large fluctuations could result in continued declining trend in campsite area, and could result in crowding and adverse effects on solitude similar to Alternative A; CAI = 0.15.	More frequent HFEs and lower fluctuations could increase campsite area, reduce crowding, and improve solitude compared to Alternative A; CAI = 0.38.	Similar to Alternative C; CAI = 0.36.	More frequent HFEs than Alternatives A and B, but fewer than other alternatives. Higher fluctuations than all but Alternative B. Combination would result in an increase in campsite area relative to Alternatives A and B, but lower than other alternatives; CAI = 0.30.	The combination of frequent HFEs and steady seasonally adjusted flows are expected to result in an increase in campsite area and reduction in campsite crowding compared to Alternative A. Steady flows also aid trip planning, helping to avoid crowding; CAI = 0.41.	The combination of frequent HFEs and steady year-round flows are expected to result in the largest increase in campsite area and least campsite crowding of all alternatives. Steady flows also aid trip planning, helping to avoid crowding; CAI = 0.45.

4-283

TABLE 4.11-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Encounters with other groups at rapids due to low flows (8,000 cfs) as indicated by the navigation index (NI)	No change from current conditions; intermediate rank among alternatives; NI = 0.50 out of 1.	More encounters than Alternative A; NI = 0.39.	Fewer encounters than Alternative A; NI = 0.75.	Similar effect as Alternative A; NI = 0.45.	Most encounters due to highest frequency of low flows; NI = 0.37.	Fewer encounters than Alternative A because steady flows mostly above 8,000 cfs; NI = 0.71.	Fewest encounters because of steady flows nearly always above 8,000 cfs; NI = 0.96.
Effect of daily fluctuations as indicated by the fluctuation index (FI)	No change from current conditions; intermediate effect among alternatives, FI = 0.79 out of 1	Highest effect, FI = 0.42 .	Almost no effect, FI = 0.93	Similar to Alternative A, FI = 0.74	Second-highest effect, FI = 0.57.	No effect; steady daily flows, FI = 1.0	No effect; steady daily flows, FI = 0.98
Disturbance from non-flow actions: vegetation management, mechanical removal of trout, and administrative trips	No change from current conditions; no vegetation restoration actions, few mechanical removals of trout.	Higher effects than Alternative A due to vegetation restoration actions; and few mechanical removals of trout.	Higher effects than Alternative A, due to vegetation restoration actions and potentially more mechanical removals of trout.	Higher effects than Alternative A due to vegetation restoration actions and more mechanical removals of trout.	Higher effects than Alternative A due to vegetation restoration actions and potentially more mechanical removals of trout.	Lower effects than Alternative A due to absence of mechanical removals of trout, but greater effects due to vegetation restoration actions.	Higher effects than Alternative A due to vegetation restoration actions and more mechanical removals of trout.

4-284

1 have the lowest fluctuation index values, indicating the lowest frequency of fluctuations within
2 the preferred range (Figure 4.10-1). Alternative D would include testing of sustained steady
3 flows for invertebrate production during weekend days from March through August, and these
4 steady flows would reduce any impacts of fluctuations on wilderness experience on those days.
5 Because most daily fluctuations under all alternatives are below the 10,000-cfs level (flows
6 $\geq 10,000$ cfs were identified as being perceived as less natural by Bishop et al. 1987), the
7 fluctuation index, which was developed for whitewater rafting for effects of fluctuations on such
8 factors as navigation and camping, is not a perfect surrogate for evaluating perceived naturalness
9 of flows. Visitors would be expected to notice that high daily fluctuations are not natural;
10 however, the overall effects of such perceptions on wilderness experience are likely fairly small.
11

12 A metric (time off river) was developed to quantify the relative amount of time rafters
13 would have to explore and enjoy wilderness at the end of each day (Section 4.10.1). Roberts and
14 Bieri (2001) demonstrated that groups spent 50% less time off river at a flow of 8,000 cfs,
15 compared to a flow of 19,000 cfs. Evaluation of the flow patterns of the LTEMP alternatives
16 demonstrated that there would be very little difference among alternatives for this metric, except
17 under Alternative F, which has elevated flows during the peak boating season. This similarity
18 among alternatives is likely due to the fact that each has similar mean annual flows of between
19 10,000 and 15,000 cfs.
20

21 Non-flow experimental actions, including mechanical removal of trout, experimental
22 vegetation restoration activities, and administrative trips related to monitoring and data collection
23 needed for the GCDAMP. Mechanical removal trips would also present less natural conditions to
24 visitors related to noise and visual disturbances. Vegetation restoration activities, proposed by
25 NPS as an experimental, pilot effort to determine the effectiveness of vegetation control and
26 restoration efforts, would occur under all alternatives except for Alternative A. They would
27 temporarily adversely affect wilderness experience while the activities were ongoing and until
28 restoration activities were discontinued, either because they had achieved a level of success that
29 produced natural vegetation communities, or because they were ineffective.
30

31 Alternative A would have the lowest impacts from non-flow experimental actions,
32 because vegetation restoration is not included in the alternative. Alternative F would have
33 impacts that were slightly higher than Alternative A, but lower than the remaining alternatives,
34 because this alternative does not employ mechanical trout removal. Alternatives B, C, D, E, and
35 G would have the highest levels of such impacts, which would be comparable under these
36 alternatives.
37

38 Considering the effects of flow fluctuation overall, the steady flow Alternatives F and G
39 would rank as having generally lower adverse effects on wilderness experience than the
40 fluctuating flow alternatives, because the latter alternatives have effects on a daily basis. This
41 advantage is reduced somewhat, but not entirely, by the higher frequency of HFES under
42 Alternative F and of HFES and TMFs under Alternative G as compared to the fluctuating flow
43 Alternatives A–E. Of the fluctuating flow alternatives, Alternative A would have the lowest
44 effects from fluctuating flows due to moderate daily fluctuations, few HFES, and no TMFs.
45 Alternatives B, C, D, and E would have comparable effects from fluctuations, with Alternative B
46 having the greatest effect from high daily fluctuations, but the fewest HFES of these alternatives.

1 Considering sand retention and potential increase in sandbar area, which is also an effect
2 of flows and flow fluctuations, benefits related to sand retention and increases in sandbar area
3 would be lowest under Alternatives A and B, which would have relatively few HFEs that would
4 build bars and relatively high fluctuating flows that would erode bars. Benefits would be
5 intermediate under Alternatives C, D, and E, which have more HFEs to build sandbar area than
6 Alternatives A and B. Benefits would be greatest under Alternatives F and G, which would have
7 steady flows and the most frequent HFEs. Crowding and loss of solitude would decrease with
8 increasing sandbar area.

9
10 While the metrics discussed above provide an analytical tool to evaluate and differentiate
11 the LTEMP alternatives with regard to effects on visitor wilderness experience, actual
12 differences for most visitors would be small and many of the disturbances evaluated—including
13 HFEs, TMFs, mechanical trout removals, and vegetation management—would be infrequent,
14 short-term actions that would not affect most visitors. In addition, few visitors would be expected
15 to experience more than one of these disturbances, as a given action of one type typically
16 excludes the other actions at a given time (e.g., a TMF would not occur at the same time as an
17 HFE or likely within the time period of a single trip).

18 19 20 **4.11.3 Alternative-Specific Impacts**

21
22 The following Section provides descriptions of impacts summarized above as they are
23 expected to occur under each of the LTEMP alternatives. The alternatives are compared in terms
24 of the relative rankings of the various wilderness experience effects and measures considered,
25 rather than in absolute terms.

26 27 28 **4.11.3.1 Alternative A (No Action Alternative)**

29
30 Under Alternative A (the No Action Alternative), the HFE protocol would expire in
31 2020. It is expected that implementation of the protocol up to its expiration would help reverse
32 the ongoing trend of declining campsite area, but the declining trend would resume after the
33 protocol expired. Any increase in crowding would reduce opportunities for solitude and
34 primitive, unconfined recreation under this alternative.

35
36 Alternative A, with a navigation index of 0.50 (Figure 4.10-1), ranks in the middle of the
37 LTEMP alternatives, indicating a relatively high tendency for low flows to lead to encountering
38 other groups at rapids under Alternative A. The navigation index is a seasonally weighted
39 measure of the frequency of minimum daily flows greater than 8,000 cfs, identified as the flow
40 below which navigation risks increase (Appendix J.2.2).

41
42 Similarly, Alternative A ranks in the middle of alternatives with regard to daily
43 fluctuation levels, with a fluctuation index of 0.79 (Figure 4.10-1); a majority of days would be
44 within the daily range of fluctuations preferred by whitewater rafters (Section J.2.3 in
45 Appendix J), which would also maintain a sense of naturalness as identified by Bishop et al.
46 (1987). This ranking is consistent with allowed daily fluctuations under the respective

1 alternatives. With respect to experimental flows, Alternative A has the lowest projected number
2 of HFEs and no TMFs that would negatively affect wilderness experience.

3
4 Alternative A would have the second lowest impacts on wilderness experience from non-
5 flow actions overall among the alternatives. Alternative A has no TMFs, a low expected number
6 of mechanical removal trips, and no experimental vegetation restoration actions. The number of
7 administrative trips expected under this alternative would be comparable to that of other
8 alternatives.

9
10 In summary, Alternative A has the lowest potential to increase campsite area and a
11 corresponding decrease in visitor solitude, and a moderate tendency for crowding at rapids due to
12 periods of lower flows. Alternative A would have moderate adverse effects from daily flow
13 fluctuations and experimental flows on wilderness experience, and has the lowest adverse effects
14 from non-flow experimental actions on wilderness experience as a result of having the lowest
15 combined number of such actions.

16 17 18 **4.11.3.2 Alternative B**

19
20 Alternative B would have a relatively low potential to retain and build sandbar area,
21 similar to that for Alternative A, and would be expected to continue a long-term trend of
22 increasing campsite crowding due to erosion. The low tendency to retain sand and build beaches
23 is attributable to the low number of projected HFEs over the 20-year LTEMP period (an average
24 of 7.2) and high daily fluctuations. Any increase in crowding would reduce opportunities for
25 solitude under this alternative.

26
27 Alternative B, with a navigation index of 0.39 (Figure 4.10-1), has one of the highest
28 tendencies for low flows to lead to encountering other groups at rapids. Any such effect,
29 however, would lead to only small effects on wilderness experience, because frequency of
30 encounters would be slightly increased, short term, and low impact.

31
32 Alternative B, with a fluctuation index of 0.42 (Figure 4.10-1), would have the fewest
33 days within the daily range of fluctuations preferred by whitewater rafters, which also maintains
34 a sense of naturalness as identified by Bishop et al. (1987), resulting in a high relative potential
35 to reduce a sense of naturalness among the alternatives. With respect to experimental flows,
36 Alternative B has the second lowest projected number of HFEs and a moderate number of TMFs
37 that would negatively affect wilderness experience.

38
39 The number of non-flow experimental actions and administrative trips under
40 Alternative B would be higher than under Alternative A, but comparable to, or in the case of
41 mechanical removals of trout less than, those under other alternatives. As for other alternatives,
42 the effects of these actions on wilderness experience are expected to be localized and short-term
43 and to affect relatively few visitors each year. Vegetation restoration would also have a slight
44 long-term potential benefit from restoring wilderness character via native vegetation.

1 In summary, Alternative B has the second lowest potential to increase campsite area and
2 preserve visitor solitude, while having among the highest tendencies for crowding at rapids due
3 to low flows. Alternative B would have among the highest adverse effects from daily flow
4 fluctuations and experimental flows on wilderness experience, and is comparable to, or lower
5 than, most other alternatives with respect to adverse effects of non-flow experimental actions on
6 wilderness experience.

9 **4.11.3.3 Alternative C**

10
11 Alternative C is expected to have a relatively high potential to retain sand and build
12 sandbar area (exceeded only slightly by Alternatives F and G) and is expected to reverse the
13 trend in declining campsite area. This high potential results from the high frequency of HFEs (an
14 average of 21.3 over the LTEMP period) and moderate within-day fluctuations in flow. This
15 increase in camping area would improve opportunities for solitude.

16
17 Alternative C, with a navigation index of 0.75 (Figure 4.10-1), has a relatively low
18 tendency for encounters at rapids, and thus a relatively low potential to affect solitude.

19
20 Alternative C, with a fluctuation index of 0.93 (Figure 4.10-1), ranks third among
21 alternatives; most days would be within the daily range of fluctuations preferred by whitewater
22 rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a
23 correspondingly low potential to reduce a sense of naturalness due to high daily flow
24 fluctuations. With respect to experimental flows, Alternative C has the second-highest projected
25 number of HFEs and a moderate to high number of TMFs that would negatively impact
26 wilderness experience.

27
28 The number of non-flow experimental actions and administrative trips under
29 Alternative C would be higher than under Alternative A, but comparable to those under other
30 alternatives. As for other alternatives, the effects of these actions on wilderness experience are
31 expected to be localized and short term, and to affect relatively few visitors each year.

32
33 In summary, Alternative C has a relatively high potential to increase campsite area and
34 preserve visitor solitude, while having a low tendency for crowding at rapids due to low flows.
35 Alternative C would have among the lowest adverse effects on wilderness experience from daily
36 flow fluctuations and experimental flows, and is comparable to most other alternatives with
37 respect to adverse effects of non-flow experimental actions on wilderness experience.

40 **4.11.3.4 Alternative D (Preferred Alternative)**

41
42 Alternative D is expected to have a relatively high potential to retain sand and build
43 sandbar area, similar to Alternatives C, F, and G, and is expected to reverse the trend in declining
44 campsite area. This high potential results from a high number of projected HFEs over the next
45 20 years (an average of 21.1), similar to Alternative C, and moderate within-day fluctuations.
46 This increase in camping area would improve opportunities for solitude.

1 Alternative D, with a navigation index of 0.45 (Figure 4.10-1), would be comparable to
2 Alternative A with regard to encounters at rapids, and would represent little change from current
3 conditions.

4
5 Alternative D, with a fluctuation index of 0.74 (Figure 4.10-1), ranks fifth among
6 alternatives, just below Alternative A; a majority of days would be within the daily range of
7 fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as
8 identified by Bishop et al. (1987) and a correspondingly low potential to reduce a sense of
9 naturalness due to high daily flow fluctuations. With respect to experimental flows,
10 Alternative D has the second-highest projected number of HFEs (tied with Alternative C) and a
11 moderate number of TMFs that would negatively affect wilderness experience.

12
13 The number of non-flow experimental actions and administrative trips under
14 Alternative D would be higher than under Alternative A, but comparable to those under other
15 alternatives. As for other alternatives, the effects of these actions on wilderness experience are
16 expected to be localized and short term, and to affect relatively few visitors each year.

17
18 In summary, Alternative D has a relatively high potential to increase campsite area and
19 preserve visitor solitude, while having a moderate tendency for crowding at rapids due to low
20 flows. Alternative D would have moderate adverse effects from daily flow fluctuations and
21 experimental flows on wilderness experience, and is comparable to most other alternatives with
22 respect to adverse effects of non-flow experimental actions on wilderness experience.

23 24 25 **4.11.3.5 Alternative E**

26
27 Alternative E is expected to have a moderate potential to retain sand and build sandbar
28 area, slightly lower than Alternatives C, D, F, and G, and would be similarly expected to reverse
29 the trend in declining campsite area. This moderate potential results from a medium number of
30 projected HFEs over the next 20 years (an average of 17.1) and daily fluctuations somewhat
31 higher than Alternatives A, C, and D, but lower than Alternative B. This increase in camping
32 area would improve opportunities for solitude under this alternative.

33
34 Alternative E, with a navigation index of 0.37 (Figure 4.10-1), would have the highest
35 tendency for low flows to lead to encountering other groups at rapids relative to the other
36 alternatives.

37
38 Alternative E, with a fluctuation index of 0.57 (Figure 4.10-1), ranks sixth among
39 alternatives, above only Alternative B; about half of days would be within the daily range of
40 fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as
41 identified by Bishop et al. (1987) and a high relative potential to reduce a sense of naturalness
42 due to high daily flow fluctuations. With respect to experimental flows, Alternative E has a
43 moderate number of HFEs and a moderate number of TMFs that would negatively affect
44 wilderness experience

1 The number of non-flow experimental actions and administrative trips under
2 Alternative E would be higher than under Alternative A, but comparable to those under other
3 alternatives. As for other alternatives, the effects of these actions on wilderness experience are
4 expected to be localized and short term, and to affect relatively few visitors each year.
5

6 In summary, Alternative E has a moderate potential to increase campsite area and
7 preserve visitor solitude, while having a relatively high tendency for crowding at rapids due to
8 low flows. Alternative E would have relatively moderate to high adverse effects from daily flow
9 fluctuations and experimental flows on wilderness experience, and is comparable to most other
10 alternatives with respect to adverse effects of non-flow experimental actions on wilderness
11 experience.
12
13

14 **4.11.3.6 Alternative F**

15
16 Alternative F is expected to have the second-highest potential to retain sand and build
17 beach area and would be similarly expected to reverse the trend in declining campsite area. This
18 high potential results from a high number of projected HFEs over the next 20 years (an average
19 of 38.1) and steady flows. This increase in camping area would improve opportunities for
20 solitude under this alternative. Steady flows under this alternative will aid in trip planning, which
21 will also help avoid crowding.
22

23 Alternative F, with a navigation index of 0.71 (Figure 4.10-1), would have lower
24 tendency for low flows to lead to encountering other groups at rapids than other alternatives,
25 except Alternatives C and G.
26

27 Alternative F, with a fluctuation index of 1.0 (Figure 4.10-1), ranks highest among
28 alternatives; essentially all days would be within the daily range of fluctuations preferred by
29 whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al.
30 (1987) and effectively no potential to reduce a sense of naturalness due to high daily flow
31 fluctuations under this steady-flow alternative. With respect to experimental flows, Alternative F
32 has the highest number of HFEs but no TMFs that would negatively affect wilderness
33 experience.
34

35 The number of non-flow experimental actions and administrative trips under
36 Alternative F would be higher than under Alternative A, but lower than those under other
37 alternatives because this alternative would not feature mechanical trout removal. As for other
38 alternatives, the effects of these actions on wilderness experience are expected to be localized
39 and short term, and to affect relatively few visitors each year.
40

41 In summary, Alternative F has a high potential to increase campsite area and preserve
42 visitor solitude, while having a low tendency for crowding at rapids due to low flows.
43 Alternative F would have no adverse effects from daily flow fluctuations but some effects from
44 the highest number of HFEs on wilderness experience, and is lower than most other

1 alternatives with respect to adverse effects of non-flow experimental actions on wilderness
2 experience.

3 4 5 **4.11.3.7 Alternative G** 6

7 Alternative G is expected to have the highest potential to retain sand and build sandbar
8 area and would be most likely of all alternatives to reverse the trend in declining campsite area.
9 This high potential results mainly from a high number of projected HFEs over the next 20 years
10 (an average of 24.5) and steady flows. This increase in camping area would improve
11 opportunities for solitude under this alternative. Steady flows will aid in trip planning, which will
12 also help avoid crowding.

13
14 Alternative G, with a navigation index of 0.96 (Figure 4.10-1), would have the lowest
15 tendency of all alternatives for low flows to lead to encountering other groups at rapids.

16
17 Alternative G, with a fluctuation index of 0.98 (Figure 4.10-1), ranks second among
18 alternatives, slightly below Alternative F; nearly all days would be within the daily range of
19 fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as
20 identified by Bishop et al. (1987) and effectively no potential to reduce a sense of naturalness
21 due to high daily flow fluctuations under this steady-flow alternative. With respect to
22 experimental flows, Alternative G has the second-highest number of HFEs and highest number
23 of TMFs that would negatively affect wilderness experience.

24
25 The number of non-flow experimental actions and administrative trips under
26 Alternative G would be higher than under Alternative A, but comparable to those under other
27 alternatives. As for other alternatives, the effects of these actions on wilderness experience are
28 expected to be localized and short term, and to affect relatively few visitors each year.

29
30 In summary, Alternative G has a high potential to increase campsite area and preserve
31 visitor solitude, while having the lowest tendency for crowding at rapids due to low flows.
32 Alternative G would have no adverse effects from daily flow fluctuations, but some effects from
33 the second-highest number of HFEs on wilderness experience; it is comparable to all alternatives
34 except Alternatives A and B with respect to adverse effects of HFEs and comparable to other
35 alternatives with respect to effects of non-flow experimental actions on wilderness experience.

36
37

1 **4.12 VISUAL RESOURCES**
2

3 This section describes the assessment of
4 the potential effects of the alternatives on visual
5 resources, concentrating on changes that could
6 occur to the water, select geological features, and
7 areas of riparian vegetation along the shore lines
8 of the Colorado River, Lake Powell, and
9 Lake Mead.

10
11 Visual resources are important to visitor
12 enjoyment of GCNRA, GCNP, and LMNRA, and
13 the conservation of visual resources is an
14 important component of federal management
15 activities for these areas. For this reason, it is
16 important to understand how dam operations and
17 non-flow management actions may affect visual resources within the project area. Indicators of
18 effects on visual resources include the height of the calcium carbonate ring surrounding Lake
19 Mead and Lake Powell, the exposure of lake deltas in Lake Mead and Lake Powell, the exposure
20 of Cathedral-in-the-Desert in Lake Powell, and potential impacts associated with changes in
21 vegetation and water color, clarity, and surface appearance.

22
23 Calcium carbonate deposits form at the water line and are typically visible at lake
24 elevations below full pool, where they create a bathtub ring effect. They are generally lighter in
25 color than the walls without calcium carbonate deposits. This creates visual contrast that may
26 result in visual impacts. The calcium carbonate deposits around both Lake Powell and
27 Lake Mead will be more or less exposed as lake levels rise and fall; however, the exposure will
28 be most affected by future hydrology. In order to quantify the extent of visibility of the calcium
29 carbonate rings, the average end-of-month elevation of each reservoir over the 20-year LTEMP
30 period was modeled, and from this the potential range in height of the exposed calcium carbonate
31 ring (the distance from the top of the ring to the water level) was determined. Projected
32 elevations were compared against both lakes at full pool. Lake Powell is considered at full pool
33 at 3,700 ft AMSL. Lake Mead is considered at full pool at 1,221 ft AMSL.

34
35 Our analysis indicates that the lake elevations would vary very little under the different
36 alternatives, resulting in very little difference in the potential maximum height of the calcium
37 carbonate ring. For Lake Powell, the potential difference in the maximum height of the ring
38 varies approximately 1 ft among the alternatives. For Lake Mead, the potential difference in the
39 maximum height of the ring varies approximately 3 ft among the alternatives. The calcium
40 carbonate deposits produce a visual contrast regardless of their height and size and make up only
41 a portion of the view in both lakes, and the overall difference in visual impacts among the
42 alternatives as a result of exposure of the rings would be negligible.

43
44 Lake deltas appear as expansive, eroding sediment deposits that become more visible as
45 the water level in the reservoir decreases. They are considered a visual detractor
46 (Reclamation 2007a). The size of a lake delta is directly affected by the mass of sediment

Issue: How do the alternatives affect visual resources?

Impact Indicators:

- The heights of the calcium carbonate rings surrounding Lake Mead and Lake Powell
- Exposure of lake deltas in Lake Mead and Lake Powell
- Exposure of Cathedral-in-the-Desert in Lake Powell
- Changes in vegetation and sandbar size

1 delivered to the delta, and its exposure is directly affected by lake elevation. Lake deltas within
2 Lake Powell and Lake Mead will be more or less exposed as lake levels fall and rise; however,
3 the exposure of the lake deltas will be most affected by future hydrology. The increased visibility
4 of lake deltas creates increased visual contrast and may result in visual impacts. In order to
5 quantify the extent of the visibility of lake deltas, the average end-of-month elevation of each
6 reservoir over the 20-year LTEMP period was modeled to determine if lake deltas would be
7 more or less exposed in each of the reservoirs.
8

9 The analysis indicates that Lake Powell elevations would vary approximately 1 ft among
10 the alternatives, while Lake Mead elevations would vary approximately 2 ft among the
11 alternatives. Lake deltas produce visual contrast regardless of their height and size and make up a
12 very small part of the views in both lakes. On the basis of predicted variation in lake elevations,
13 there would be little, if any, difference in the exposure of lake deltas in either lake among the
14 alternatives, and the overall difference in visual impact among the alternatives as a result of
15 exposure of lake deltas would be negligible.
16

17 Cathedral-in-the-Desert is a prominent geological feature in Lake Powell that attracts
18 many visitors when exposed. The feature is exposed when the Lake Powell reservoir elevation is
19 $\leq 3,550$ ft AMSL (Reclamation 2007a). Because of the attention Cathedral-in-the-Desert
20 receives when it is exposed, the exposure of this feature could be perceived as a positive impact
21 or benefit. To determine the potential exposure of Cathedral-in-the-Desert, the average number
22 of months per year that Lake Powell's end-of-month elevation was $\leq 3,550$ ft AMSL over the
23 20-year LTEMP period was modeled. Our analysis indicates that Cathedral-in-the-Desert would
24 be potentially exposed an average of 2 months per year over the 20-year LTEMP period under all
25 alternatives, and the overall difference in visual impact between the alternatives would be
26 negligible for Cathedral-in-the-Desert and similar attractions within the lake basin.
27

28 Vegetation plays an important role in the scenic experience along the Colorado River.
29 Vegetation increases the visual interest of many places where it occurs by adding variety in color
30 and texture in contrast to the river, rocks, and bare canyon walls. Flow variations and non-flow
31 management actions can alter the type and frequency of vegetation along the corridor
32 (see Section 3.6.2 and Section 4.6). Changes in vegetation could result in different levels of color
33 and texture in contrast to the surrounding landscape, but it is difficult to predict how this could
34 affect a visitor's visual experience and is not expected to vary significantly among alternatives. It
35 is not possible to predict what types of vegetation are more appealing than others to
36 recreationists. Individuals are often influenced by their personal experiences and/or expectations,
37 and what is visually pleasing to one individual may not be to another. Potential impacts on
38 vegetation were assessed based on professional judgment and the riparian vegetation assessment
39 presented in Section 4.6.
40

41 Although frequent visitors to the Canyons, such as Tribal members, river guides,
42 scientists, and anglers, will likely notice a change in plant states and sandbar size, it is not certain
43 that an individual participating in a once-a-year or once-in-a-lifetime river trip will notice any
44 change unless there are vegetation management activities underway during visitor trips. Visitors
45 standing at scenic overlooks with views of the river may notice vegetation or sandbars in the
46 corridor, but they will be unlikely to notice a change in vegetation state or sandbar size from

1 these locations, given their distance from the river. Therefore, visual impacts on the canyons
2 from changes in vegetation or sandbar size are expected to be negligible under all alternatives.

3
4 NPS management actions that are being proposed in the river corridor of Glen and Grand
5 Canyons as well as on Hualapai lands, such as nonnative plant removal, native plant
6 revegetation, and mitigation at cultural sites, may have effects on the visual environment. These
7 effects are associated primarily with the alteration of the forms, colors, and textures of
8 vegetation, both immediately after implementation of management activities and over longer
9 time periods, because of changes in species composition, but, as discussed above, the visual
10 effects of changes in vegetation type and cover would be negligible.

11
12 Based on this analysis, the effects are considered negligible for all of the visual resources
13 indicators and would not vary among the alternatives.

14 15 16 **4.13 HYDROPOWER**

17
18 This section describes the potential
19 impacts of changes in Glen Canyon Dam
20 operations on the economic value of the
21 powerplant's capacity and energy production.
22 Impacts are measured in terms of changes in
23 regional power system capacity expansion
24 pathways,¹⁰ in overall system-level electricity
25 production costs, and in the amount of generation
26 and associated economics at the Hoover Dam
27 Powerplant. This section also discusses how
28 changes in system resources and operations affect
29 both wholesale electricity rates paid by utilities
30 that purchase firm capacity and energy from
31 Western and the retail electricity rates paid by
32 entities that contractually receive and consume
33 capacity and energy from Glen Canyon Dam.

Issue: How do alternatives affect hydropower resources?

Impact Indicators:

- Changes in the amount (MWh) and dollar value of hydropower generation at Glen Canyon Dam
- Changes in SLCA/IP marketable capacity
- Changes in capital and operating costs that Western's customers incur to serve their loads
- Changes in residential electricity bills of Western's customers
- Changes in generation and economics at Hoover Dam.

34 35 36 **4.13.1 Analysis Methods**

37
38 This section describes the methods used to estimate the impact of alternative Glen
39 Canyon Dam operating criteria on the economic value of its hydropower resources and to
40 estimate the impacts on retail electricity rates charged by entities that purchase power from the
41 Salt Lake City Area Integrated Projects (SLCA/IP or federal preference power). This section also
42 describes the methods used to estimate the impact of alternative operating criteria at Glen
43 Canyon Dam on Hoover Dam generation and economics.

¹⁰ A capacity expansion pathway is a specification of the size, timing, and type of generating units to be constructed over a specified planning horizon.

1 **4.13.1.1 Hydropower Resource and Capacity Expansion Impacts**
2

3 For each of the proposed alternative operating criteria, the hydropower impact analysis
4 estimated the net present value (NPV) of the cost of meeting future energy and capacity demands
5 of utilities (customers) that have long-term firm (LTF) contracts to purchase power from
6 Western’s SLCA/IP facilities (Section 3.13) and compared these costs to the NPV of costs under
7 the existing operating criteria (Alternative A, the No Action Alternative).
8

9 A number of models and spreadsheet tools were used for the analysis, including:

- 10 • *Colorado River Simulation System (CRSS)* simulated future hydrological
11 conditions for the six large SLCA/IP facilities that include the Seedska-dee
12 Project (Fontenelle) and the five Colorado River Storage Project (CRSP)
13 facilities; namely, Glen Canyon Dam, Flaming Gorge Dam, and the Aspinall
14 Cascade (Blue Mesa, Morrow Point, and Crystal Dams).
15
- 16 • *Sand Budget Model* scheduled the type and timing of HFEs at Glen Canyon
17 Dam and reallocated monthly water release volumes from CRSS, and revised
18 monthly elevations to enable higher water releases during months with HFEs.
19 Another type of experiment at Glen Canyon Dam, TMFs, were also added at
20 this stage.
21
- 22 • *GTMax-Lite* optimized the economic value of hourly energy produced at the
23 five largest CRSP facilities. This model determined an hour-by-hour pattern
24 of both generation (in MWh) and water releases (in cfs) that satisfied the
25 operating constraints imposed by each alternative, such as up/down ramp
26 rates, maximum change in the release over a rolling 24-hour period, maximum
27 hourly release, and others. This model consisted of two configurations: one
28 for Glen Canyon Dam and one for the remaining four CRSP facilities and
29 Fontenelle.
30
- 31 • *AURORAxmp (Aurora)* simulated the operation of the power system modeled
32 in the analysis and was also used to project hourly spot market prices in the
33 Western Interconnect. The model can be run in the capacity expansion mode,
34 in which the paths to model projected system capacity expansion meet future
35 electricity demands, or in the unit dispatch mode, to simulate powerplant unit
36 operations needed to serve the load and to minimize total electricity
37 production cost. The model was developed by EPIS, Inc., and is commonly
38 used by utilities throughout the United States.
39
- 40 • *Other specialized models and spreadsheet models* developed for the LTEMP
41 analysis included:
42 – Representative Trace Tool: selected the most representative trace or
43 hydrological future of all traces simulated by CRSS and the Sand Budget
44 Model (SBM).
45

- 1 – Hydropower Outage Model: simulated unit outages, both scheduled
- 2 maintenance and forced outages, at the six large SLCA/IP facilities.
- 3 – Hourly Load Forecast Algorithm: determined hourly loads of Western’s
- 4 customers over the study period.
- 5 – Western Marketable Capacity spreadsheet: estimated the amount of firm
- 6 capacity from all SLCA/IP facilities that Western could offer its customers
- 7 at an assumed risk preference or exceedance level.
- 8

9 More detail on each model and tool can be found in Appendix K, Sections K.1.4 and K.1.5.

10 A number of simplifying assumptions were made for the hydropower analysis, as

11 follows:

- 12
- 13
- 14 • The geographic scope of the analysis was limited to the service territories of
- 15 utilities with which Western currently has LTF electricity contracts. Limiting
- 16 the analysis to Western’s customers allows the analysis to concentrate on the
- 17 systems most affected by a DEIS alternative with an adequate level of fidelity
- 18 to obtain good estimates of economic impacts. In addition, the hourly
- 19 economic value of energy which drives much of SLCA/IP operations was
- 20 estimated by a tangential modeling task that encompasses the entire Western
- 21 Interconnect.
- 22
- 23 • Given the comparative insignificance of Glen Canyon Dam power generation
- 24 relative to the amount of electricity in the Western Interconnect power grid,
- 25 the analysis assumes that the operation of Glen Canyon Dam has an
- 26 insignificant influence on the marginal value of electricity in the system as a
- 27 whole.
- 28
- 29 • Western’s customers are separated into two categories: large and small. Large
- 30 customers, which comprise about 75% of firm capacity and energy sales, were
- 31 modeled more rigorously than small customers. The eight largest customers
- 32 are Deseret Generation and Transmission Cooperative (Deseret), the Navajo
- 33 Tribal Utility Authority (NTUA), Salt River Project (SRP), Utah Associated
- 34 Municipal Power Systems (UAMPS), Utah Municipal Power Agency
- 35 (UMPA), Platte River Power Authority, Tri-State Generation and
- 36 Transmission Association (Tri-State), and Colorado Springs Utilities (CSU).
- 37 There are about 130 remaining “small customer” entities accounting for the
- 38 remaining 25% of LTF sales. Individually, each small customer receives less
- 39 than 2.5% of the total, but proportionally, the CRSP resource is on average a
- 40 much larger component of the customer’s total resource portfolio than the
- 41 larger customers.
- 42
- 43 • The CRSS model was used to project 105 monthly hydrological traces over a
- 44 48-year period from 2013 through 2060 for three sediment traces, namely,
- 45 high, moderate, and low. Each trace contains a unique historical chronological
- 46 time sequence of hydrological conditions. Therefore, hydrological conditions

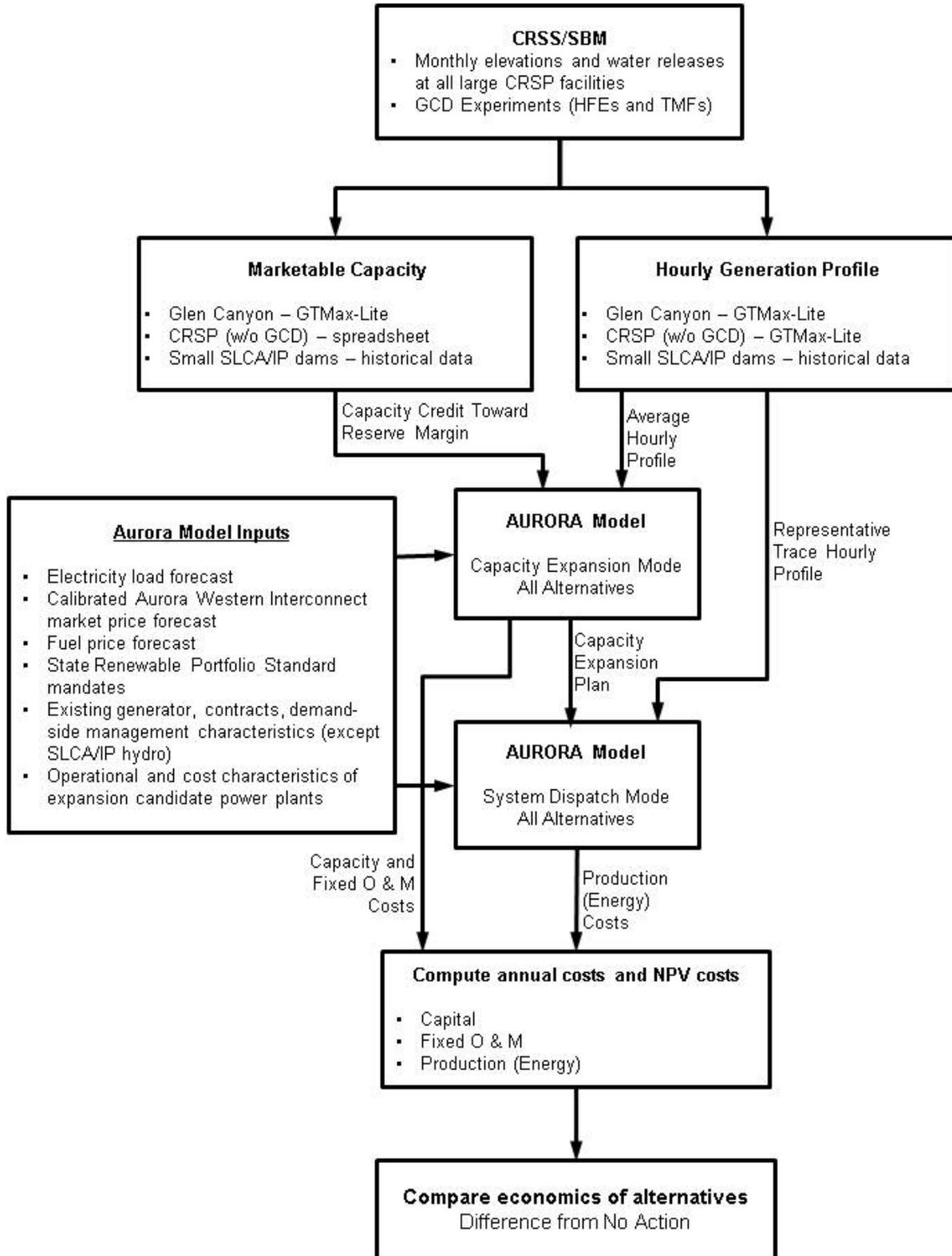
1 are deterministic, and it is extremely unlikely that any one trace will ever be
2 repeated. Of these 105 traces, a common set of 21 was used to estimate the
3 level of marketable/firm capacity of the CRSP plants and the Fontenelle
4 powerplant. To estimate the hourly value of Glen Canyon Dam energy
5 production, the AURORA model was run in dispatch mode using a
6 representative hydrological trace. The trace chosen best met a set of criteria
7 for being “representative,” and included a significant distribution of
8 hydrological conditions that are very similar to the hydrological distribution of
9 the 21 traces. Also, the mean of the representative trace is approximately
10 equal to the mean of all 21 traces. Furthermore, the AURORA model run will
11 only use the moderate sediment trace, which was estimated to have a 63.1%
12 chance of occurring. Using a single sediment trace greatly expedites model
13 runs by reducing the number of cases to be examined.

- 14
15 • This analysis uses the GTMax-Lite model to simulate the hourly operation of
16 Glen Canyon Dam and the remaining hydropower facilities that comprise both
17 the CRSP and Fontenelle powerplant. This model was designed specifically
18 for the LTEMP DEIS and consists of two configurations. One configuration
19 models only the operation of Glen Canyon Dam, and the other configuration
20 models the remaining aforementioned facilities. This is a simplification for
21 power production because Western schedules and Reclamation dispatches all
22 of the CRSP power units concurrently and incorporate some operating goals
23 and guides that are not represented by GTMax-Lite.
- 24
25 • The methodology assumes that the electrical utilities being modeled engage in
26 unfettered exchange with perfect information about the entire system when it
27 comes to exchanging electrical energy and sharing capacity. In reality, each
28 utility makes its own autonomous decisions with imperfect knowledge about
29 competing utilities. Transmission constraints are also not explicitly modeled;
30 neither are institutional nor regulatory obstacles to trade.

31
32 Figure 4.13-1 shows the modeling sequence and data flows for the power systems
33 analysis. The following section briefly describes the methodology; a more detailed discussion of
34 the methodology can be found in Appendix K, Sections K.1.4 and K.1.5.

35
36 Another noteworthy assumption is that “emergency exception criteria” as stipulated
37 under the 1996 Record of Decision will continue under all LTEMP alternatives. Therefore, Glen
38 Canyon Dam will be allowed to operate outside of minimum and maximum flow limits, daily
39 change constraints, and both maximum hourly up- and down-ramp rates in the event of a power
40 system emergency (e.g., grid energy imbalance events).

41
42 Alternative-specific Glen Canyon Dam operating criteria would affect the timing of
43 powerplant additions in the SLCA/IP system and system operation. Both would result in
44 economic impacts that are measured by the AURORA model—the core tool used for power
45 systems analysis. If the operating criteria under each alternative result in a reduction in peak
46 output from Glen Canyon Dam, new generating capacity would be needed elsewhere in the



1
 2 **FIGURE 4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP DEIS**

1 system to meet SLCA/IP peak loads. Alternative operating criteria could also change the timing
2 of Glen Canyon Dam generation, i.e., less power generated in the high price peak demand hours
3 of the day and more generated in the low price off-peak hours. Such a change in hydropower
4 operation may cause other powerplants, typically fossil-fuel thermal units, to increase generation
5 in peak hours and decrease generation in off-peak hours. The differences in the timing of new
6 resources and in the way the system is dispatched mean that the cost of reliably meeting
7 SLCA/IP loads over the 20-year LTEMP period would differ from system operations under the
8 existing operating criteria. Therefore, for each alternative, AURORA was used for two major
9 purposes: (1) to determine the capacity expansion pathway over time during the study period for
10 a joint Western/LTF customer system; and (2) to perform a least-cost unit commitment and
11 system dispatch for a given expansion pathway and a single representative hydrology future or
12 trace.

13
14 Considerable amounts of data were needed for the AURORA model runs, including:

- 15 • Hourly electricity load forecasts for all Western's LTF customer utilities
- 16
- 17 • Western Interconnect electricity market price forecasts (spot market prices
18 were projected using a configuration of AURORA representing the entire
19 Western Interconnect and a spreadsheet model that calibrated those prices to
20 historical 2013 observations at the Palo Verde market hub, which is the hub
21 closest to Glen Canyon Dam)
- 22
- 23 • Fuel price projections
- 24
- 25 • State-mandated renewable resource requirements
- 26
- 27 • Characteristics of contracts that customer utilities have with other utilities and
28 with other Western offices other than SLCA/IP
- 29
- 30 • Characteristics of demand-side management programs
- 31
- 32 • Operational and cost characteristics of powerplants owned by customer
33 utilities
- 34
- 35 • Operational and cost characteristics of powerplants customer utilities may be
36 considered for system expansion to meet future loads
- 37
- 38

39 More details on data sources and how data was generated can be found in Appendix K,
40 Sections K.1.6.1 and K.1.6.3.

41
42 Although the AURORA model has its own database of powerplant characteristics, fuel
43 price projections, and hourly load profiles for a number of areas within the entire Western
44 Interconnect, these data were compared to publicly available data sources to verify accuracy and
45 consistency. Such data sources include those available from the Energy Information
46 Administration (EIA) as well as integrated resource plans (IRPs) that Western's customers

1 provide Western or post on their company website. Since the methodology modeled Western's
2 eight large customers in detail, it was necessary to carefully examine the powerplant
3 characteristics in the AURORA inventory and benchmark them against data compiled by EIA
4 and in IRPs.
5

6 Due to the complexities of SLCA/IP hydropower operating criteria and mandates
7 unrelated to power production, AURORA could not model the dispatch of these resources at a
8 level of detail that is required for this study. Therefore, the GTMax-Lite model and other
9 spreadsheet models were used to project powerplant-specific hourly production levels over the
10 study period. The results of these models were input to AURORA as a time series of fixed hourly
11 energy injections into the power grid. Data for these models for each alternative came from the
12 CRSS model and the Sand Budget Model and included monthly reservoir elevations and water
13 release volumes and also the type and timing of experiments at Glen Canyon Dam. Outages, both
14 scheduled maintenance and forced outages, at Glen Canyon Dam and the other large SLCA/IP
15 facilities were modeled. Since alternatives only targeted the operation of Glen Canyon Dam, the
16 generation at all other SLCA/IP was typically the same in every alternative. However, in some
17 situations, when Glen Canyon Dam could not provide spinning reserves and/or regulation
18 services, a portion or all of these grid services were provided by powerplants in the Aspinall
19 Cascade, affecting operations of these facilities.
20

21 SLCA/IP marketable/firm capacity was an input to the AURORA expansion model.
22 Marketable capacity is the amount of hydroelectric capacity that Western is obligated to provide
23 to LTF customers regardless of the state or condition of SLCA/IP resources. It is also the amount
24 of capacity credited toward meeting the system reserve margin, the spare capacity above the
25 annual coincidental peak of the electric power system modeled. For this study, the reserve
26 margin was assumed to be 15%, which is a typical value in the Western Interconnect. Because
27 Western markets the capacity and energy produced by all 11 SLCA/IP facilities as a package,
28 marketable capacity was determined for the entire facility group. The GTMax-Lite model results
29 were used to compute the capacity contribution from Glen Canyon Dam, while a spreadsheet
30 using CRSS and Sand Budget Model results were used to compute the contribution from the
31 other large CRSP facilities. Historical data were used to compute marketable capacity from the
32 small SLCA/IP facilities; namely, Deer Creek, Elephant Butte, Towaoc, McPhee, and Molina.
33 Because alternatives only affected Glen Canyon Dam's operation under almost all
34 circumstances, only the contribution of Glen Canyon Dam to marketable capacity varied by
35 alternative.
36

37 Western must carefully choose the level of marketable capacity it offers because it is
38 obligated to supply this LTF capacity to its customers regardless of hydrological conditions. If
39 SLCA/IP resources are unable to supply the specified amount of capacity, Western must
40 purchase power to cover the shortfall. Western is exposed to market risks because the future of
41 both reservoir conditions and the operating state of generating units are not known with
42 certainty. Risk exposure is measured as the probability that Western will not be able to meet its
43 LTF obligations during peak summer load months. A retrospective study performed by Argonne
44 on marketable capacity currently offered by Western over the last 10 years shows that it markets
45 capacity at a 90% exceedance level. That is, Western has enough SLCA/IP capacity to meet its
46 obligation 90% of the time. Therefore, this LTEMP analysis used an exceedance level of 90% to

1 determine marketable capacity. Marketable capacity at 50% and 99% exceedance levels were
2 also modeled, and these results are presented in Appendix K, Section K.1.10.4.

3
4 Hourly generation profiles from all SLCA/IP facilities were an input to both the
5 AURORA expansion and dispatch models. The hourly profile based on the average of all
6 21 hydrology traces is input to the expansion model, and the hourly profile based on the
7 representative trace is input to the dispatch model. The appropriate configuration of GTMax-Lite
8 is used to compute the hourly generation profiles for Glen Canyon Dam and for the other large
9 CRSP facilities.

10
11 The results of the AURORA expansion model run in expansion mode were capacity
12 expansion plans for each alternative over the study period. The plans specify the type of plant
13 built (such as combustion turbines, combined cycle plants, coal plants, nuclear powerplants,
14 etc.), the capacity of the plant, and the year it begins operating. The model also computed the
15 annual capacity investment and fixed operation and maintenance (O&M) costs for the new units
16 over the study period. The AURORA model was given a wide selection of plants from which to
17 choose future capacity additions, including conventional and advanced natural gas combustion
18 turbines, conventional and advanced gas/oil combined cycle plants, scrubbed and pulverized coal
19 plants, integrated gasification combined cycle plants, nuclear powerplants, wind turbines, and
20 solar thermal and photovoltaic powerplants. More details on the powerplant expansion
21 candidates and their cost and performance characteristics are provided in Appendix K,
22 Section K.1.6.3.

23
24 The capacity expansion plan for each alternative was an input to the AURORA run in
25 dispatch mode to simulate the operation of the system for every hour in the entire study period
26 for a single hydrological future or trace, which is known as the representative trace. Because the
27 dispatch was run for only a single hydrological trace, selection of the trace is very important.
28 Trace 14 was selected as the representative trace. More detail on the method used to select the
29 representative trace can be found in Appendix K, Attachment K-3.

30
31 Results of the AURORA dispatch model consisted of costs to produce the electrical
32 energy to meet the system load demand. Production costs are the sum of powerplant fuel costs,
33 variable O&M costs, and cost of power purchased from the spot market. Results from the
34 AURORA expansion and dispatch models (namely, capital, fixed O&M, and production or
35 energy costs) were combined to determine the total annual costs for each alternative. The net
36 present value stream of costs was also calculated to facilitate comparison of each alternative to
37 Alternative A. This single lump-sum value was based on a discount rate of 3.375%, a rate that is
38 used by Reclamation for cost-benefit studies of projects. A second discount rate of 1.4%, a
39 nominal or real discount rate, was used in a sensitivity study; the results of which are presented
40 in Appendix K, Section K.1.10.5.

41 42 43 **4.13.1.2 Wholesale Rate Impacts**

44
45 The economic impact of changed operations at the Glen Canyon Dam Powerplant on
46 electrical power production and value is the impact—measured in dollars—on the economy. It

1 includes the system cost of changing the value of electrical power produced at Glen Canyon
2 Dam as a result of changing the timing and routing of water releases. It also includes the expense
3 of constructing (or savings resulting from forgoing construction of) additional electrical
4 generators because of changes in firm SLCA/IP federal hydropower capacity. Wholesale rates¹¹
5 impacts describe how these economic impacts are distributed to utilities that purchase Glen
6 Canyon Dam electrical power from the federal government at the SLCA/IP rate. The change in
7 SLCA/IP rate among alternatives reflects the economic costs of altered Glen Canyon Dam
8 operations.
9

10 Western sets rates as low as possible consistent with sound business principles to repay
11 the federal government's investment in generation and transmission facilities in addition to
12 specific non-power costs that power users are legislatively required by Congress to repay, such
13 as irrigation costs that are beyond the irrigators' ability to repay. Sales of federal electric power
14 and transmission repay all costs (including interest) associated with generating and delivering the
15 power. Western prepares a power repayment study (PRS) for each specific power project to
16 ensure the rates are sufficient to recover expenses.
17

18 It is assumed that Western will pay all of the economic costs associated with an
19 alternative and adjust firm electric service (FES) rates to pass these costs onto its FES customers.
20 These costs include all net purchased power, capital costs, fixed O&M costs, and interest
21 expense. Interest expense is calculated by multiplying each investment's prior year unpaid
22 balance by the appropriate interest rate. Computations of total purchase power for each
23 alternative are based on projections of total hourly generation from all SLCA/IP hydropower
24 resources and hourly FES customer loads. The difference between hourly generation and load is
25 resolved by hourly non-firm energy transactions at an energy price projected by the power
26 systems economic analysis. All capital costs and fixed O&M costs associated with a reduction in
27 Glen Canyon Dam Powerplant capacity are also paid by Western and passed on to its customers
28 via adjustments to FES wholesale rates. See Appendix K, Section K.2, for more detailed
29 information on the PRS and wholesale rate modeling process.
30

31 Several calculations were performed to determine the impact of the LTEMP DEIS
32 alternatives on the SLCA/IP rate. Three rates were calculated for each of the seven alternatives:
33 (1) a firm energy rate, (2) a firm capacity rate, and (3) a composite rate. The SLCA/IP FES rate
34 is the price paid per unit of product sold by Western's CRSP Management Center to its SLCA/IP
35 FES customers. These calculations and analyses were performed by Western CRSP Management
36 Center staff.
37

38 Western markets SLCA/IP electrical power under firm, long-term contracts. Under these
39 contracts, Western is required to deliver this electrical power to federal points of delivery
40 regardless of hydrological conditions or changes in the operational criteria of the SLCA/IP
41 hydropower plants. The current FES marketing contracts expire on September 30, 2024. For the

¹¹ The term "rate" will be used rather than "price." This is the standard convention for wholesale electrical commodities. Rate is the price charged for an energy unit, whether capacity or energy. Rate is often used to describe wholesale prices because it is the price of wholesale units and not necessarily the units used for retail sales.

1 period following 2024, Western is currently engaged in developing a marketing plan. This
2 requires a formal public process in compliance will applicable federal law.

3
4 Several assumptions had to be made in order to estimate LTEMP DEIS impacts. First, it
5 was assumed that Western will continue with its current SLCA/IP obligations until the current
6 marketing period ends and the existing contracts expire.¹² This requires that Western deliver the
7 same amount of electrical power and energy to SLCA/IP customers until the end of fiscal year
8 (FY) 2024, regardless of the alternative analyzed. Recognizing uncertainties about Western’s
9 future marketing of SLCA/IP resources between 2025 and 2034, net firming expenses for the
10 post-2024 time period were analyzed under two sets of assumptions. These are as follows:

- 11
12 1. A continuation of existing SLCA/IP FES contract commitments between
13 FY 2025 and FY 2034 (referred to as No Change or “NC” in
14 Section 4.13.2.4); and
- 15
16 2. A reduction in SLCA/IP FES contract commitments so that net firming
17 expenses are equal to \$0 between FY 2025 and FY 2034. This means, for the
18 numbers included in the SLCA/IP power repayment study, zero dollars of
19 firming expense and zero additional dollars of revenue from market sale or
20 from available hydropower sales (referred to as Resource Available or “RA”
21 in Section 4.13.2.4).

22
23 These two assumptions constitute “bookends” regarding the outcomes possible in the
24 development of the post-2024 marketing plan.¹³ These bookends are for modeling purposes
25 only. They represent a very broad range of possible FES obligations of electrical power in the
26 post-2024 marketing period. The bookends will almost certainly encompass the actual rate
27 impact, once the post-2024 marketing plan is completed. It should be noted that the
28 establishment of these bookends is not an attempt to predict or to anticipate Western’s choice
29 prior to the conclusion of the required public process.

30 31 32 **4.13.1.3 Retail Rate Impacts**

33
34 Western markets power to utilities serving approximately 5.8 million retail customers in
35 Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming (Reclamation 2012d).
36 Customers are small and medium-sized towns that operate publicly owned electrical systems,
37 irrigation cooperatives, and water conservation districts; rural electrical associations or

12 There is a provision in the existing SLCA/IP contracts to modify the FES obligations upon a 5-year notice to SLCA/IP customers. However, considering the probable timing of new operating criteria for the Glen Canyon Dam following the completion of the LTEMP DEIS and the issuance of a ROD a 5-year notice would not be significantly different than the end of the current marketing period.

13 Western could choose a post-2024 SLCA/IP FES obligation of electric power that exceeds its current obligation. However, prior to completion of the required public process it would be difficult to determine what the higher obligation would be that could be considered a reasonable bookend.

1 generation and transmission cooperatives who are wholesalers to these associations; federal
2 facilities such as Air Force bases, universities, and other state agencies; and Indian Tribes.
3

4 The effect of reductions in available generating capacity at Glen Canyon Dam under each
5 of the alternatives on retail electricity rates and bills for customers of municipal, cooperative, and
6 other entities receiving power from Western was estimated in four steps. First, a detailed
7 database of retail revenues and sales was developed for 226 utility systems that directly or
8 indirectly receive an allocation of Salt SLCA/IP preference power including American Indian
9 Tribes. This database was combined with aggregate production costs (variable O&M costs,
10 purchased power, and fuel expenses), capital investments for capacity additions, and fixed O&M
11 costs derived from the AURORA analysis. Second, capacity additions were converted to revenue
12 requirements using a carrying charge analysis (see Appendix K, Section K.3.1) along with the
13 capital cost of different investments. Third, the cost of changing Glen Canyon operations under
14 each alternative was distributed to each retail utility system by simulating the Western SLCA/IP
15 capacity and energy allocation process. Fourth, overall rate impacts to individual utility systems
16 (including Tribal Systems) were allocated to residential and non-residential consumers to
17 compute retail rate and bill impacts. The process of using a carrying charge analysis along with
18 aggregate production costs does not require SLCA/IP wholesale rates. Use of production costs
19 and carrying charges results in somewhat higher rate impacts than estimation that uses SLCA/IP
20 wholesale rates.
21

22 The objective of the retail rate impact analysis is to measure the change in electric bills
23 that consumers who ultimately use electricity in their homes or businesses will incur because of
24 changes in the way Glen Canyon Dam operates. Retail rate impacts can be measured directly
25 from the change in capacity and energy costs that are computed in the power systems analysis
26 along with the utility carrying charges. This direct method of computing retail rate impacts
27 involves allocating changes in energy and capacity cost to distribution systems and then dividing
28 the cost changes by retail revenues. All of the economic impacts come from the capacity cost
29 (including fixed O&M) and energy cost changes (including ancillary service values). Using this
30 method, additional evaluation of Western wholesale rates is unnecessary to derive retail rate
31 impacts (although direct use of SLCA/IP wholesale rates computed by Western would result in
32 lower impacts). The power systems simulations combined with the carrying charge rate analysis
33 applied to new capacity resulting from Glen Canyon Dam operation changes measures impacts
34 on wholesale power cost that must ultimately be attributed directly to retail ratepayers.
35 Appendix K includes an example demonstrating the intuitive result that the method of directly
36 computing retail rates or alternatively using a multi-step process of using capacity and energy
37 costs to first evaluate Western wholesale rates results in an appropriate measured retail rate
38 impact, even though measured rate impacts are lower through using SLCA/IP rates computed by
39 Western.
40

41 While the process of computing retail rate impacts from the capacity and energy cost
42 changes implies changes in capacity allocation, under current contract provisions with customer
43 utilities, Western may maintain the same capacity allocation to each customer entity. Given this
44 contractual obligation, Western rather than the individual utilities may have to replace the lost
45 capacity at Glen Canyon Dam by purchasing the shortfall from other sources. Eventually, these
46 increased costs would be passed on to entities who are allocated preference power and rates

1 would have to be increased because of capacity and energy cost. This process of assuming that
2 Western would pay for the capacity and energy costs associated with changes in Glen Canyon
3 Dam operations results in the same retail rate impacts as the assumption that the wholesale cost
4 impacts are simply paid by the utilities themselves as long as Western would pass on the costs as
5 they are incurred. If Western would defer the cost increases, the changes in energy and capacity
6 costs would still be paid, but with a temporary deferral that would presumably include financing
7 costs. Attempting to incorporate potential deferral strategies in Western's wholesale rate policy
8 is neither appropriate nor practical in assessing retail rate impacts. For example, if capacity costs
9 and production costs increase, but Western incurs the cost for a period of years but then later
10 increases the rate including cost of capital, it would not be appropriate to include the deferral in
11 the rate impacts. Finally, in order to provide a relative benchmark indication of the effects of
12 Glen Canyon Dam capacity cost changes on costs incurred to purchase power, the average
13 aggregate capacity and energy costs are measured relative to amount of money that Western
14 currently collects from capacity and energy allocations (see Appendix K for details).

17 **4.13.1.4 Hoover Dam Impacts**

18
19 Hoover Dam is located about 370 mi downstream of Glen Canyon Dam. Changes from
20 current monthly water release volumes under LTEMP alternative operating criteria could impact
21 pool elevations in Lake Mead, and these in turn could impact Hoover Dam Powerplant firm
22 capacity and energy generated by water releases through its turbines. A modeling tool of Hoover
23 Powerplant monthly operations was developed to provide estimates of impacts of the LTEMP
24 DEIS alternatives on Hoover Powerplant economics. The tool, referred to here as the Hoover
25 Powerplant Model, computes two economic metrics; namely, firm capacity and energy, both in
26 terms of NPV, for each alternative and compares the results.

27
28 To perform the analysis data on monthly water releases from Hoover Dam, end-of-month
29 elevations at Lake Mead were obtained from CRSS and the Sand Budget Model for all
30 21 hydrology traces for each alternative over the study period. Using information from
31 Reclamation, algorithms were developed relating reservoir elevation to reservoir storage and to
32 maximum powerplant capacity. The Hoover Powerplant Model used this information to
33 determine the difference in monthly generation between Alternative A and each of the other
34 alternatives for all 21 hydrology traces. The Western Interconnect electricity market price
35 forecasts, which are identical to the prices used in the Aurora model simulation of Western's
36 eight large customers, were used in the Hoover Powerplant Model to compute the value of the
37 generation from the Hoover Powerplant. The value of monthly generation was computed by
38 multiplying the monthly energy generation by the market price of electricity, accounting for the
39 difference in price between energy generated in peak hours versus off-peak hours. Based on
40 information from Reclamation, it was assumed that 95% of generation at the Hoover Powerplant
41 takes place in peak hours and only 5% in off-peak hours.

42
43 The Hoover Powerplant Model also computed the firm capacity available from the
44 Hoover Powerplant based upon the relationship between reservoir elevation and maximum
45 powerplant output derived from data provided by Reclamation. The maximum monthly capacity
46 was computed for all 21 hydrology traces over the study period. It was assumed that below a

1 pool elevation of 1,050 ft the maximum output is zero, and above an elevation of 1,205 ft the
2 maximum output remains constant at 2,075 MW, which is the maximum powerplant capacity. To
3 be consistent with the Glen Canyon Powerplant power systems analyses, this analysis assumed
4 that the firm hydropower capacity of the Hoover Powerplant is based on the 90th percentile
5 exceedance level in the peak month of August. More details on the modeling methodology and
6 the results are presented in Appendix K, Section K.4.

9 **4.13.2 Summary of Hydropower Impacts**

10
11 This section and Table 4.13-1 summarize the potential impacts of alternative operating
12 criteria on Glen Canyon Dam's hydropower resources. These impacts are measured in terms of
13 changes in both powerplant capacity and generation and associated economic value. Impacts are
14 analyzed from an overall systems perspective in which least-cost electricity production costs are
15 computed and regional power system capacity expansion pathways are determined. This section
16 also discusses how changes in system resources and operations, caused by operational changes at
17 Glen Canyon Dam, impact the retail electricity rate that Western's wholesale customers charge
18 to their end-use customers. Table 4.13-1 does not include the rate impacts on American Indian
19 Tribes; they are discussed separately in Appendix K, Section K.3.

22 **4.13.2.1 Monthly Water Release Impacts**

23
24 Differences among LTEMP alternatives do not occur from annual water release volumes,
25 but rather from the routing and timing of these water releases during monthly, daily, and hourly
26 timeframes. The total volume of water released from Glen Canyon Dam over the 20-year
27 LTEMP period is essentially identical under all LTEMP alternatives. Also, differences among
28 alternatives in annual water release volumes are less than 1%. However, alternatives significantly
29 impact the timing of water releases within a year. For example, as compared to Alternative A,
30 Alternative F releases much higher water volumes during March, April, May, and June and much
31 lower water volumes during July and August. Alternatives also impact the daily profile of water
32 releases. Changes in operating criteria such as maximum and minimum release restrictions and
33 mandates that limit water release changes over time result in very different release patterns
34 during most days. For example, Alternative F requires water releases from Glen Canyon Dam to
35 be at a constant rate an entire day. In contrast, Alternative A allows powerplant operators to
36 change water release levels during a day such that power production more closely matches
37 wholesale rate customer energy requests and/or in response to the market price of electricity.

38
39 Lastly, alternatives affect the routing of water releases from the dam. Water is typically
40 released through one or more of the powerplant's eight turbines to produce electricity. However,
41 dependent on the pressure exerted by the water elevation in Lake Powell, turbines have a limited
42 amount of water that can flow through them during an hour. Also, the generating capacity of a
43 unit indirectly limits the flow of water through it. Therefore, whenever a water release is required
44 to exceed the combined flow capabilities of the generating units that are in operation, some of
45 the water is released through bypass tubes and spillways. These non-power releases produce no

1 **TABLE 4.13-1 Summary of Impacts of LTEMP Alternatives on Hydropower Resources**

Impact Indicator	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
	(No Action Alternative)			(Preferred Alternative)			
Overall summary of impacts	No change from current condition. Second highest marketable 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. No change in the value of generation at Hoover Dam.	Compared to Alternative A, 3.8% increase in marketable capacity and decrease in total cost to meet electric demand over the 20-year LTEMP period. Small decreases in both the average electric retail rate and the average monthly residential electricity bill in the year of maximum rate impact. No change in the value of generation at Hoover Dam.	Compared to Alternative A, 17.5% decrease in marketable capacity and increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 2.0% increase in the value of generation at Hoover Dam	Compared to Alternative A, 6.7% decrease in marketable capacity and increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.0% increase in the value of generation at Hoover Dam	Compared to Alternative A, 12.2% decrease in marketable capacity and 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.2% increase in the value of generation at Hoover Dam	Compared to Alternative A, 42.6% decrease in marketable capacity (lowest of alternatives) and 1.2% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period. Highest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 4.1% increase in the value of generation at Hoover Dam	Compared to Alternative A, 24.2% decrease in marketable capacity and 0.73% increase in total cost to meet electric demand over 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.4% increase in the value of generation at Hoover Dam
Impacts on Generation and Capacity							
Annual average daily generation (MWh) ^a	11,599 (no change from current condition)	11,567 (0.3% decrease)	11,506 (0.8% decrease)	11,477 (1.1% decrease)	11,521 0.7% decrease	11,379 (1.9% decrease)	11,403 (1.7% decrease)
SLCA/IP Marketable capacity (MW) ^b	737.2 (no change from current condition)	765.3 (3.8% increase)	608.1 (17.5% decrease)	687.6 (6.7% decrease)	647.0 (12.2% decrease)	423.1 (42.6% decrease)	558.2 (24.2% decrease)
SLCA/IP Replacement Capacity (MW) ^c	Not applicable	-28.1	129.1	49.6	90.2	314.1	179.0

2

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Generation and Capacity (Cont.)							
System-level generating capacity additions (MW) ^d	4,820 (no change from current condition)	4,820 (no change from current condition)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,280 (9.5% increase)	5,050 (4.8% increase)
Impacts on Power System Economics							
SLCA/IP system-wide production cost (\$million) ^e	34,228 (no change from current condition)	34,221 (0.02% decrease)	34,255 (0.08% increase)	34,270 (0.1% increase)	34,249 (0.06% increase)	34,373 (0.4% increase)	34,345 (0.3% increase)
SLCA/IP Capital cost (\$million) for capacity expansion ^e	1,643 (no change from current condition)	1,635 (0.5% decrease)	1,746 (6.3% increase)	1,696 (3.2% increase)	1,703 (3.7% increase)	1,882 (14.5% increase)	1,769 (7.7% increase)
Fixed O&M cost (\$million) for capacity expansion ^e	345 (no change from current condition)	344 (0.3% decrease)	363 (5.2% increase)	354 (2.6% increase)	355 (2.9% increase)	385 (11.6% increase)	366 (6.1% increase)
Total cost (\$million) ^e	36,216 (no change from current condition)	36,200 (0.04% decrease)	36,364 (0.41% increase)	36,320 (0.29% increase)	36,307 (0.25% increase)	36,640 (1.2% increase)	36,480 (0.73% increase)
Difference in Total Costs (\$million) Relative to No Action	Not applicable	-16	148	104	91	424	264
Local Hydropower Value (\$million) ^f	2,662 (no change from current condition)	2,657 (0.2% decrease)	2,614 (1.8% decrease)	2,613 (1.8% decrease)	2,620 (1.6% decrease)	2,540 (4.6% decrease)	2,556 (4.0% decrease)
Impacts on Wholesale Rates							
Energy (\$/kWh)							
NC ^g	13.52	13.54	13.99	13.94	13.84	15.67	16.07
RA ^h	13.40	13.22	14.55	13.78	14.01	16.86	15.22
Average	13.46	13.38	14.27	13.86	13.93	16.27	15.65
Capacity (\$/kW)							
NC	5.74	5.75	5.94	5.92	5.88	6.66	6.83
RA	5.69	5.62	6.18	5.85	5.95	7.16	6.50
Average	5.72	5.69	6.06	5.89	5.92	6.91	6.67

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Electric Retail Rate Payers							
Percent change in retail rates (maximum impact year) ⁱ	No change from current conditions	-0.27%	0.43%	0.39%	0.50%	1.21%	0.64%
		2029	2025	2023	2027	2018	2025
Change in monthly residential bill (maximum impact year) ^j	No change from current conditions	-\$0.27	\$0.40	\$0.38	\$0.47	\$1.02	\$0.59
Impacts on Hoover Powerplant Economics							
Total value of generation (\$million) ^k	2,362.3 (0% change)	2,362.3 (0% change)	2,408.6 (2.0% increase)	2,384.2 (1.0% increase)	2,390.2 (1.2% increase)	2,451.1 (4.1% increase)	2,392.0 (1.4% increase)
Change in value of generation (\$million) ^k	No change from current conditions	Same as Alternative A	46.4	21.9	27.9	88.8	29.7

- ^a Average daily Glen Canyon Dam generation under representative hydrological conditions.
- ^b Marketable capacity is calculated based on all 21 hydrology traces with median sediment input (sediment trace 2), which has the highest likelihood of occurrence. It is calculated at the 90% exceedance level, which means if Western was contractually obligated to provide this amount of LTF capacity in the peak month of August, it would meet that obligation 90% of the time.
- ^c Lost capacity is the difference between the marketable capacity in Alternative A and the marketable capacity of another alternative; it represents the capacity that would need to be replaced somewhere in the power system if that alternative was implemented.
- ^d Additional generation capacity required under the LTEMP alternatives for Western's customers over the 20-year LTEMP period to not only meet future load demand but also account for loss/gain in capacity at Glen Canyon Dam due to the alternative operating constraints.
- ^e Net present value (\$million 2015) of costs to meet total system electric demand over 20-year study period for all SLCA/IP customers under representative trace. Discount rate is 3.375%.
- ^f Net present value of electricity generated at Glen Canyon Dam over the 20-year LTEMP period (\$million 2015).
- ^g NC = no change from current LTF commitment levels.
- ^h RA = commitment level equals available SLCA/IP federal hydropower resource.
- ⁱ The unweighted average percent changes in retail rates relative to Alternative A across all systems with available data for the year with the highest percentage impact.
- ^j The average change in residential electric bills (2015 dollars) relative to average residential bills in Alternative A for the year with the maximum rate impact (residential bills are not weighted by utility size).
- ^k Net present value of electricity generated at Hoover Dam over the 20-year LTEMP period (\$million 2015).

1 energy and are referred to as spilled water. Each alternative has a unique set of HFE
2 specifications that affect the frequency and duration of Glen Canyon Dam water spill volumes.

3
4 Spilled water can also occur under very low (i.e., dry) hydropower conditions when the
5 Lake Powell elevation is below a minimum turbine water intake level. All of the water is
6 released through bypass tubes and, therefore, no electricity is produced until the water level rises
7 to a minimum intake level.

8 9 10 **4.13.2.2 Hydropower Power Generation and Capacity Impacts**

11
12 The first section of Table 4.13-1 summarizes the impacts of changes in Glen Canyon
13 Dam operations under each alternative on hydropower generation and capacity. Under
14 Alternative A, the average daily generation at Glen Canyon Dam over the 20-year study period is
15 projected to be 11,599 MWh under representative conditions; that is, the monthly water releases
16 and generation levels expected under one of the 21 analyzed hydrology traces, trace 14, which
17 was considered representative of the full range of annual inflow volumes over the 20-year
18 LTEMP period. On average, this represents 72.8% of the generation produced by all SLCA/IP
19 hydropower resources over the 20-year LTEMP study period. With the remaining alternatives,
20 generation would vary between 11,567 MWh under Alternative B (a reduction of 0.3%
21 compared to Alternative A) to 11,379 MWh under Alternative F (a reduction of 1.9%) under
22 representative conditions (Table 4.13-1). These relatively small differences (i.e., less than 2%) in
23 average daily generation among the alternatives are not due to the amount of water released from
24 the dam, but largely attributed to differences in the amount of water routed through bypass tubes
25 to conduct HFEs, which, as described in the previous section, does not generate electricity.

26
27 Although there is little difference in annual average daily generation at Glen Canyon
28 Dam among the alternatives, there are monthly differences. Under representative hydrological
29 conditions, average daily generation under Alternative A ranges from 8,640 MWh in March to
30 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to
31 11,511 MWh in January (Figure 4.13-2). Although generation under Alternative B would be
32 similar to Alternative A between June and August, slightly less electricity would be generated
33 during January through May, and during October through December. In contrast with
34 Alternatives A and B, all other alternatives (except for Alternative F, which is discussed later)
35 have less average daily generation in the summer months of June, July, and August when
36 electricity demand is at its peak. Alternatives C, D, E, and G have a higher average daily
37 generation in the spring months of March, April, and May than Alternatives A and B, with
38 Alternative C generally having the highest values. Alternatives D, E, and G have higher average
39 daily generation in the fall months of October and November compared to Alternatives A and B.
40 However, in September, October, and November, Alternative C has a considerably lower
41 average daily generation than almost any other alternative. In the winter months of December,
42 January, and February, Alternatives A and B typically have a higher average daily generation
43 than most other alternatives.

44
45 Generation under Alternative F would result in the most deviation from Alternative A,
46 with a shifting of annual peak generation from the mid-summer months to late spring/early

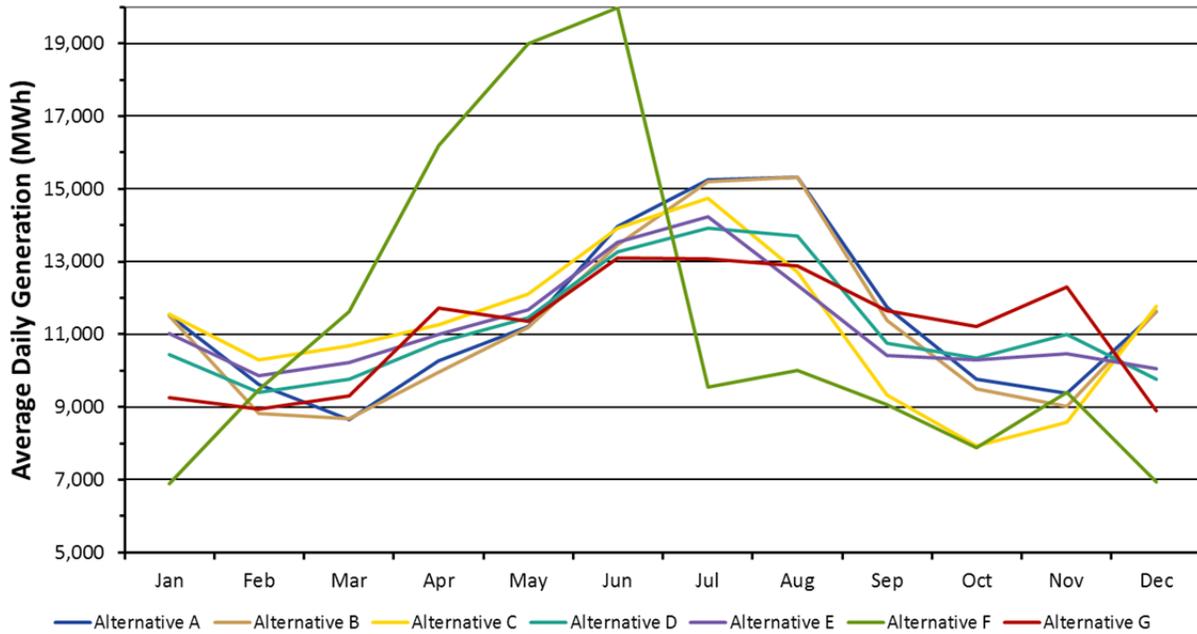


FIGURE 4.13-2 Average Daily Glen Canyon Dam Generation under Representative Hydrological Conditions under LTEMP Alternatives

summer, producing a maximum of 19,995 MWh in June, significantly higher than the peak output under Alternative A (Figure 4.13-2). By contrast, generation during the summer would fall considerably, to a low of 9,708 MWh in July, exceeding 9,000 MWh in August, September, and November and falling to just over 6,900 MWh in December and January.

Although the Glen Canyon powerplant is rated at 1,320 MW, it has been operationally restricted since 1996 and is rarely allowed to produce that amount of power (Veselka et al. 2010). This is due to several factors such as the number of units that are operable, the reservoir elevation, grid reliability considerations, and reservoir operating criteria. The latter is most important for the purposes of estimating economics under different LTEMP alternatives. However, it can produce at rated capacity during extremely high hydropower conditions and during high peak release HFEs (i.e., about 33,000 cfs and higher).

As shown in Table 4.13-1, under Alternative A, there would be about 737 MW of capacity available from the entire SLCA/IP to meet peak system loads. This capacity is based on the assumption that 90% of the time this amount of capacity or more would be available when the system peak loads occur. Under Alternatives C, D, E, F, and G, the marketable capacity would decrease to between 687.6 MW under Alternative D to 423.1 MW under Alternative F.

Except for Alternative B, under which the capacity is 28.1 MW higher than Alternative A, all other alternatives would provide approximately 50 MW to 314 MW less capacity—that is, a reduction that ranges from of 6.7% to 42.6% compared to Alternative A. Capacity differences mainly stem from the level of Glen Canyon Dam operational flexibility (daily change, ramp rates, etc.) and monthly water release volumes that are allowed under each

1 alternative in conjunction with both reservoir elevations and monthly water release levels.
2 Operations under Alternative B allow the highest level of flexibility, while Alternatives F and G,
3 which require steady flows each day, restrict capacity. This lost capacity would need to be
4 replaced somewhere in the SLCA/IP system.
5

6 SLCA/IP marketable capacity affects the amount and timing of generating units that will
7 be constructed in the future to reliably meet forecasted increases in electricity demand in the
8 service territories of Western's customer utilities and to replace the retirement of existing
9 powerplant generating capacity. Under Alternative A, an estimated 4,820 MW of new capacity
10 would be built by Western's customer utilities. System capacity expansion additions are phased
11 in over time such that a minimum 15% capacity reserve margin is attained in each year of the
12 20-year LTEMP period. Under alternatives with less SLCA/IP marketable capacity, more new
13 generating capacity must be built and the capacity would need to be built sooner. Under
14 Alternative B, 4,820 MW of new capacity would also be added by the end of the LTEMP period;
15 however, because Alternative B has slightly more marketable capacity available, one new
16 generating unit would need to be constructed a year later than under Alternative A. All other
17 alternatives have less marketable capacity than Alternative A. Under Alternatives C, D, E, and
18 G, 5,050 MW of new capacity would be required (an increase of 230 MW, or 4.8%, compared to
19 Alternative A), and under Alternative F, 5,280 MW of new capacity would be required (an
20 increase of 460 MW, or 9.5%) (Table 4.13-1). Also note that because the capacity is built in
21 sizes/increments that exceed the amount lost, system capacity expansion differences among the
22 alternatives do not typically match the amount of lost capacity. Appendix K, Section K.1.10.2,
23 provides more details and illustrations of alternative impacts on capacity expansion timing and
24 total new construction.
25

26 It is assumed that Western's eight largest wholesale customers make decisions and
27 function as a single aggregate system, and that they would build enough capacity to reliably meet
28 their total aggregate demands. The modeling of this power system assumes a very high level of
29 cooperation and coordination among Western and its LTF power customers. Capacity expansion
30 planning, unit commitment schedules, and least-cost hourly dispatch for the entire system were
31 based on a "single operator/decision maker" model. This is a higher level of cooperation and
32 coordination than what actually occurs.
33

34 **4.13.2.3 Economic Impacts**

35
36 The power systems economic analysis primarily measures the impacts of LTEMP
37 alternatives on the cost of generating energy to meet system electricity demands and to build
38 sufficient capacity to meet these demands reliably. In doing so, the analysis accounts for system
39 interactions and reactions. For example, when Glen Canyon Dam increases its output, the power
40 system analysis estimates the generation response (i.e., decrease) of other on-line powerplants in
41 the system. The economic impacts are not limited to any one individual system component, but
42 rather to the collective impacts on all components in the system over the entire study period.
43 Focus is also placed on economic differences among alternatives rather than on their absolute
44 values. Impacts measured include production costs that are incurred hourly on a continuous
45

1 ongoing basis and capacity expansion costs that occur as needed, and therefore much less
2 frequently.

3
4 Capacity expansion cost components include capital investment costs, interest, and other
5 expenses that are accrued during the time period that a generating unit is constructed, and also
6 fixed O&M costs. Since newly constructed capacity will operate long past the end of the 20-year
7 LTEMP period, these costs along with interest during construction (IDC) are annualized and
8 incurred from the time the unit comes on-line until the end of the study period. Similarly, O&M
9 costs for new units are only incurred during the study years that the units operate. Since the
10 primary focus of the analysis is on cost differences among alternatives, fixed O&M costs for
11 existing powerplants are not included, since it is assumed that these costs are identical among all
12 alternatives. In this regard, it should be noted that the AURORA model retirement schedule is
13 identical across all alternatives.

14
15 The cost of serving system loads (the production cost) under each alternative over the
16 20-year LTEMP period is shown in the second section of Table 4.13-1. Costs are expressed in
17 NPV to allow differences in the timing of generation to be normalized, using a 3.375% discount
18 rate. Except for Alternative B, total energy production cost would increase under all alternatives
19 compared to Alternative A, with increases varying from \$21 million (a 0.06% increase) under
20 Alternative E to \$145 million (a 0.4% increase) under Alternative F. System-level production
21 cost differences are a function of timing and routing of Glen Canyon Dam water releases.

22
23 In general, turbine water releases and associated generation, which occur when they have
24 the highest economic value, would decrease overall system-wide production costs. System
25 energy value in this context is the amount of money that is expended to serve all of the system
26 electricity demand. When the demand is low, it is served by generating units that have low
27 production costs; however, as electricity demand increases, units that are more expensive to
28 operate are brought on-line to serve this higher (or incremental) load. Therefore, there is a direct
29 relationship between the cost of serving more demand and the incremental cost to serve it. In this
30 economic analysis, the incremental cost to serve one more MWh of demand, electricity price,
31 and economic value are used synonymously.

32
33 When Glen Canyon Dam produces energy during periods of the year when loads and
34 prices are high, the power its produces offsets generation from more expensive units that would
35 have otherwise been utilized. In effect, this lowers overall system production costs. Likewise,
36 system production costs are lower when Glen Canyon generates energy during times of the day
37 when it has the highest economic value. Alternatives with the most operational flexibility also
38 have the highest economic value. This flexibility allows Glen Canyon Dam operators to generate
39 more energy (that is, release more of the limited water resource) during times of the day when
40 prices are highest and reduce generation when prices are low. Appendix K, Section K.1.10,
41 provides more details on market prices and the timing of Glen Canyon Dam power production
42 under each alternative.

43
44 Lastly, it should be noted that because water releases are limited, releases that bypass the
45 generators (such as in the case of most HFEs) not only have no power system economic value,
46 but also detract from turbine water releases, and hence both power production and value. In

1 summary, the economic value of Glen Canyon Dam power generation is highest when water is
2 released through powerplant turbines to produce energy which offsets generation that would
3 have otherwise been produced by generating units that are expensive to operate. The economic
4 impacts of HFEs and other experiments, including low summer flows, TMFs, and sustained low
5 flows for invertebrate production are included in the estimates of impacts under each alternative.
6 Additional discussion of the cost of experiments is presented in Section K.1.10.3 of Appendix K.
7

8 The cost of building new capacity (or capital costs) to meet the 15% system reserve
9 margin discussed in the previous section is also shown in the second section of Table 4.13-1. The
10 table also shows fixed O&M costs associated with the new construction. Both costs are
11 expressed in NPV.
12

13 Based on AURORA model runs and a review of both Western's customers' IRPs and the
14 IRPs of surrounding utility systems, new capacity additions consist of advanced natural gas-fired
15 combined cycle plants (400 MW) and advanced natural gas-fired combustion turbines
16 (230 MW). Capacity expansion pathways are carefully chosen for each alternative and consist of
17 a mix of new technologies that is consistent with those found in the IRPs of Western's large
18 customers and also with Energy Information Administration (EIA) forecasts of future generation
19 capacity in the Western Interconnect (see Appendix K, Section K.1.6.2, for more details).
20

21 Total cost, including capital, fixed O&M, and production costs, is also shown in the
22 second section of Table 4.13-1. The cost is expressed in NPV using a 3.375% discount rate.
23 Based on representative hydrological conditions, the total system cost to reliably supply electric
24 demand during the 20-year LTEMP period under Alternative A would be just over \$36.2 billion,
25 with a decrease of about \$16 million (or 0.04%) in the cost under Alternative B. Although
26 Alternative B has slightly lower monthly generation than Alternative A, its total system cost is
27 lower because it has a higher firm capacity. The higher firm capacity delays the construction of
28 an natural gas combustion turbine plant by a year compared to Alternative A. With slightly
29 higher spring and slightly lower summer average daily flows under Alternatives C, D, E, and G
30 compared to Alternative A, total costs would be slightly higher, ranging from about \$36.3 billion
31 under Alternatives D and E (an increase of about 0.3% compared to Alternative A) to over
32 \$36.6 billion under Alternative F (an increase of 1.2%), which would have higher spring and
33 early summer flows, and lower late summer and fall flows, than Alternative A.
34

35 The local value of only Glen Canyon Dam energy production under each alternative is
36 presented in the second section of Table 4.13-1. It is based on hourly generation levels and the
37 local value of energy injections into the electric grid by Glen Canyon Dam. The ranking and cost
38 differences among these alternatives do not match overall system results because they only focus
39 on Glen Canyon Dam. There is little consideration of system-level interactions and reactions.
40 Note that capital and fixed O&M costs are also not included. All alternatives have reductions in
41 the local value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period
42 compared to Alternative A. Smaller reductions in value occur under Alternatives B, C, D, and E;
43 losses in value vary from \$5 million (a 0.2% reduction) under Alternative B to \$49 million
44 (a 1.9% reduction) under Alternative D. Alternatives F and G have larger reductions in value;
45 namely, \$122 million (a 4.6% reduction) and \$106 million (a 4.0% reduction), respectively.
46

1 **4.13.2.4 Change in FES Wholesale Rates**
2

3 Through some combination of changed SLCA/IP rates under the NC bookend or lower
4 SLCA/IP commitment levels under the RA bookend, FES utilities that receive SLCA/IP
5 preference power will be impacted as a result of changed operations at Glen Canyon Dam. Under
6 the NA bookend, Western would absorb the economic costs (or reap the benefits) of an
7 alternative and adjust FES rates accordingly, passing costs/benefits to its customers. At the other
8 end of the spectrum, SLCA/IP commitment levels would be adjusted to reflect hydropower
9 resource attributes/capabilities under the RA bookend and FES customers would respond
10 through adjustments to their system dispatch and future resource expansion paths.
11

12 For each alternative, Western computed the impact of each alternative in terms of single
13 energy and capacity rates that are applied over the entire 2015 through 2034 LTEMP period.
14 This deviates from Western’s normal 5-year forecast in order to accurately capture each
15 alternative’s rate impacts. Table 4.13-1 shows FES customer rates estimated by Western RPS
16 studies under both NC and RA bookend marketing structures. The energy and capacity rates
17 reflect Western’s current method of billing. SLCA/IP FES customers are billed monthly for the
18 amount of energy used and for their capacity allocation. See Appendix K, Section K.2, for more
19 detailed information on FES wholesale rate results.
20

21 This analysis is not a description of policy or an attempt to predict Western’s post-2024
22 marketing plan. This set of bookend results is intended to reflect the range of reasonable
23 possibilities. It is reasonable that Western would continue existing commitment levels to ensure
24 continued customer access to the transmission associated with the energy. Moreover, it is also
25 reasonable to believe that Western would establish post-2024 marketing plan commitments that
26 exactly follow the power resource available at the SLCA/IP power system. For the final LTEMP
27 DEIS, assumptions concerning post-2024 commitment levels may be revised to duplicate the
28 range of impacts examined in the economic analysis.
29
30

31 **4.13.2.5 Retail Rate and Bills Impacts**
32

33 System-wide production costs, fixed operation and maintenance costs of new capacity
34 and the financing cost associated with building new plants must be incurred by entities that
35 receive SLCA/IP preference power. Costs associated with replacing generation capacity no
36 longer provided at Glen Canyon Dam ultimately increases retail rates and bills of residential and
37 non-residential customers. The retail rate impacts experienced by utility systems are not uniform
38 across different utility systems that receive federal preference power. Differential retail rate
39 impacts on particular systems from LTEMP alternatives are largely driven by the amount of
40 power that is allocated from SLCA/IP relative to the quantity of other power that is produced or
41 purchased by a particular system. If utility systems are allocated a large amount of SLCA/IP
42 capacity and energy, but because of their large size, this allocation is a small fraction of the
43 overall amount of power purchased, the retail rate impacts tend to be small. The relative
44 dependence on SLCA/IP capacity and energy varies by a wide margin across entities that receive
45 allocations. SLCA/IP energy allocation as a percent of retail sales range from 0.05% for SRP up
46 to 62% for the City of Meadow (a member of UAMPS). Impacts on the utility systems that are

1 most impacted are presented in Appendix K, Section K.3. This appendix also describes impacts
2 on Tribal systems.

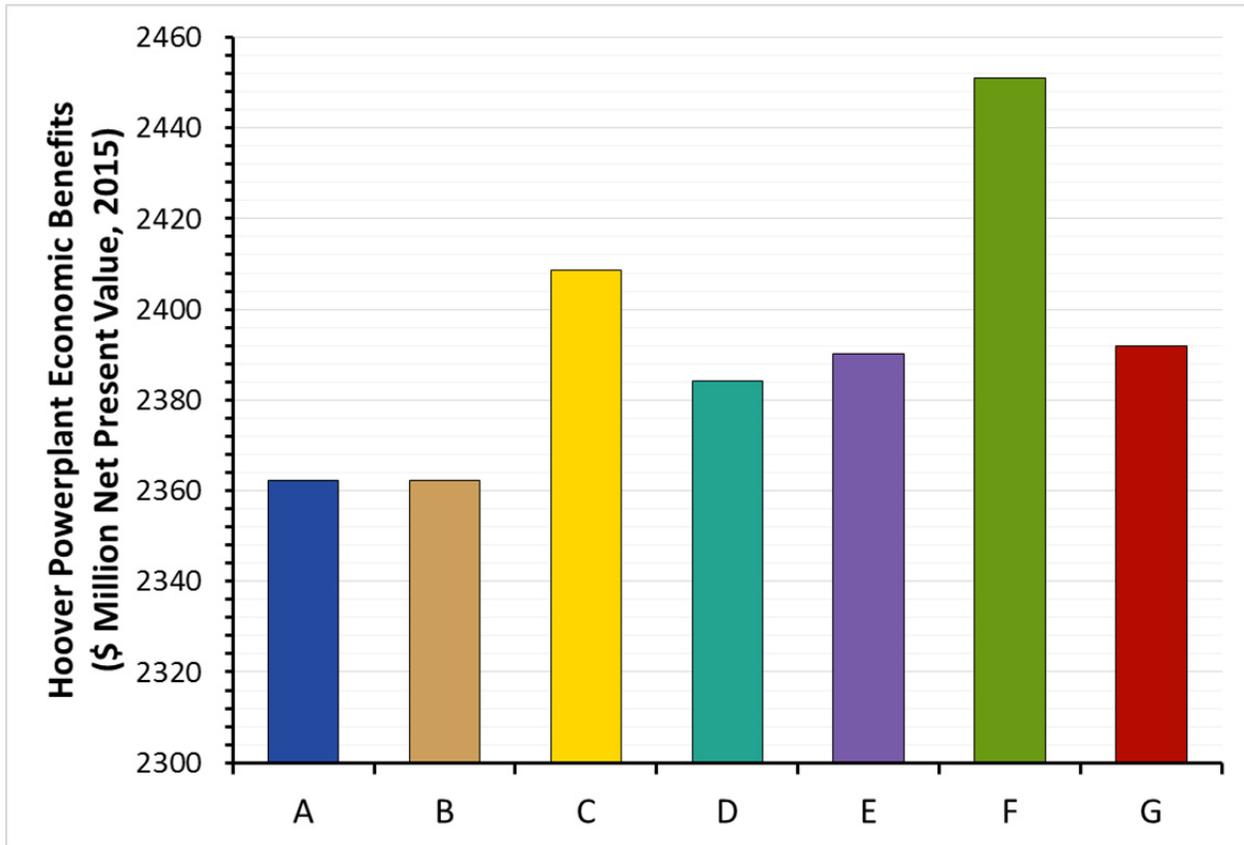
3
4 The third section of Table 4.13-1 shows impacts on retail electric rates and monthly
5 residential electricity bills for Western's preference power customers compared to Alternative A.
6 The change in retail rates and the average change in monthly residential bills are both in the year
7 of maximum rate impact. Both metrics are not weighted by utility size; that is, each utility
8 serving retail customers has the same weight. More detailed analyses of retail rates and
9 residential bills are provided in Appendix K, Section K.3.

10
11 The average change in the retail rate varies from a decrease of 0.27% in Alternative B to
12 an increase of 1.21% in Alternative F. The average change in the monthly residential electricity
13 bill varies from a decrease of \$0.27 in Alternative B to an increase of \$1.02 in Alternative F.
14 Both metrics are the average in the year of maximum rate impact. The electric bill reduction in
15 Alternative B is due to a delay of one year in constructing a new natural gas-fired combustion
16 turbine compared to Alternative A. Similarly the electric bill increase in Alternative F is due to
17 the construction of two new natural gas-fired combustion turbines over the 20-year LTEMP
18 period compared to Alternative A. Retail rate and residential bill impacts are computed from
19 adjusting data in the power systems analysis for municipal and cooperative carrying costs and
20 not from SLCA/IP wholesale prices. If estimated wholesale prices are used instead of adjusting
21 power systems cost, the measured rate impacts would be lower.

22 23 24 **4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power Economics**

25
26 The Hoover Powerplant Model used projected Lake Mead reservoir elevations over the
27 20-year LTEMP period to estimate monthly maximum physical output levels for the Hoover
28 Powerplant for all 21 hydrology traces. Assuming the firm capacity at the Hoover Powerplant is
29 based on the 90th percentile exceedance level in the peak load month of August, the model found
30 that for all alternatives the Lake Mead elevation is below the active pool level of 1,050 ft more
31 than 10% of the time. Therefore, because no generation is possible more than 10% of the time in
32 August, no firm capacity (or a firm capacity of zero) can be assigned to any alternative
33 (see Section K.4 in Appendix K).

34
35 The Hoover Powerplant Model computed the change in economic value of Hoover
36 Powerplant energy production attributed to each LTEMP alternative by multiplying the change
37 in monthly energy production by monthly market prices of energy as projected by the AURORA
38 model. Estimates are made for each month of the 20-year LTEMP period for all 21 hydrology
39 traces. To compare LTEMP alternative economics on a consistent basis, the NPV of Hoover
40 benefits were computed using a 3.375% annual discount rate, which is the same rate used for
41 computing the NPV of SLCA/IP costs. The result of NPV calculations for the Hoover
42 Powerplant is shown for each alternative in Figure 4.14-4. The NPV benefit for Hoover ranges
43 from nearly zero for Alternative B to about \$89 million for Alternative F.



1

2 **FIGURE 4.13-3 Total NPV of Hoover Powerplant Benefits over a 20-Year Period under LTEMP**
 3 **Alternatives**

4

5

6 **4.13.3 Alternative-Specific Impacts**

7

8

9

9 **4.13.3.1 Alternative A (No Action Alternative)**

10

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20

Average annual daily generation at Glen Canyon Dam is currently 11,599 MWh under representative hydrological conditions. Average daily generation ranges from 8,640 MWh in March to 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to 11,606 MWh in December (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be \$2,662 million, and would not change under Alternative A. SLCA/IP marketable capacity is currently 737.2 MW at the 90% exceedance level. Average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable capacity would not change under Alternative A.

21

22

23

Forecasted increases in electricity demand in the service territories of Western’s customer utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity built under Alternative A over the 20-year LTEMP period. Assuming representative hydrological

1 conditions, the total cost (including capital, fixed, and variable costs) to meet system electric
2 demand under Alternative A would be just over \$36.2 billion.

3
4 Because there would be no change in Glen Canyon Dam operations as a result of
5 Alternative A, there would be no impact on the wholesale rates Western charges its FES utility
6 customers, retail rates charged by Western's customer utilities, or the electric bills paid by their
7 residential customers. The average wholesale energy rate of the two bookend cases was
8 estimated to be \$13.46/kWh and the average capacity rate was estimated to be \$5.72/kW.

9
10 In summary, Alternative A would have the second-highest marketable capacity from
11 SLCA/IP and tied with Alternative B for the smallest amount of new capacity needed over the
12 20-year LTEMP period. It also would have the second-lowest total cost to meet electric demand
13 over that period, and there would be no change in either the average electric retail rate or the
14 average monthly residential electricity bill. There would be no change in the value of generation
15 produced at Hoover Dam.

16 17 18 **4.13.3.2 Alternative B**

19
20 Average annual daily generation at Glen Canyon Dam would be 11,567 MWh under
21 representative hydrological conditions. Average daily generation under representative
22 hydrological conditions would range from 8,665 MWh in March to 15,405 MWh in August,
23 before falling to 9,046 MWh in November, and then increasing to 11,608 MWh in December
24 (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year
25 LTEMP period under representative conditions would be \$2,657 million, a decrease of
26 \$5 million, or 0.2%, compared to Alternative A as explained below. SLCA/IP marketable
27 capacity would be 765.3 MW at the 90% exceedance level, which is a 28 MW, or 3.8%, increase
28 compared to Alternative A. There would therefore be slight decreases in average annual daily
29 generation and hydropower value at Glen Canyon Dam and a slight increase in SLCA/IP
30 marketable capacity compared to Alternative A under Alternative B.

31
32 Forecasted increases in electricity demand in the service territories of Western's customer
33 utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity
34 built under Alternative B over the 20-year LTEMP period. Assuming representative hydrological
35 conditions, the total cost (including capital, fixed, and variable costs) to meet electric demand
36 under Alternative B would be \$36.2 billion.

37
38 Under Alternative B, there would be a small reduction in capital and operating costs
39 associated with new capacity relative to Alternative A. Although the total amount of capacity
40 added over the 20-year LTEMP period is the same as Alternative A, there would be a 1-year
41 delay in constructing a new natural gas-fired combustion turbine. This delay accounts for the
42 slightly lower total cost of Alternative B compared to Alternative A. Also because of the
43 construction delay, the average electricity retail rate could drop by 0.27% and the average
44 monthly residential electricity bill could be reduced by an average of \$0.27. Both metrics are the
45 average in the year of maximum rate impact.

1 The average wholesale energy rate was estimated to be \$13.38/kWh, which is a decrease
2 of \$0.08/kWh (−0.6%) compared to Alternative A. The average wholesale capacity rate was
3 estimated to be \$5.69/kW, which is a decrease of \$0.03/kW (−0.5%) compared to Alternative A.
4

5 In summary, Alternative B would have the highest marketable capacity from SLCA/IP of
6 any alternative and would be tied with Alternative A for the smallest amount of new capacity
7 needed over the 20-year LTEMP period. It also would have the lowest total cost to meet electric
8 demand over that period. Both the wholesale energy and capacity rates charged by Western
9 would decrease compared to Alternative A. There would be a decrease in the average electric
10 retail rate and in the average monthly residential electricity bill compared to Alternative A in the
11 year of maximum rate impact. There would be no change in the value of generation produced at
12 Hoover Dam.
13

14 **4.13.3.3 Alternative C**

15
16
17 Average annual daily generation at Glen Canyon Dam would be 11,506 MWh under
18 representative hydrological conditions. Average daily generation under would range from
19 10,292 MWh in February to 14,855 MWh in July, before falling to 7,971 MWh in October, and
20 then increasing to 11,739 MWh in December (Figure 4.13-2). The value of electricity generated
21 by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be
22 \$2,614 million, a decrease of \$48 million, or 1.8%, compared to Alternative A. SLCA/IP
23 marketable capacity would be 608.1 MW at the 90% exceedance level, which is a 129 MW or
24 17.5% decrease compared to Alternative A. There would therefore be slight decreases in average
25 annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable
26 capacity under Alternative C compared to Alternative A.
27

28 Forecasted increases in electricity demand in the service territories of Western's customer
29 utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity
30 built under Alternative C over the 20-year LTEMP period. An additional gas turbine would be
31 needed during the LTEMP period compared to Alternative A. Assuming representative
32 hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet
33 system electric demand under Alternative C would be almost \$36.4 billion.
34

35 Because of the additional gas turbine the average retail electric rate would increase about
36 0.43% and the average monthly residential electricity bill would increase by an average of \$0.40.
37 Both metrics are the average in the year of maximum rate impact.
38

39 The average wholesale energy rate was estimated to be \$14.27/kWh, which is an increase
40 of \$0.81/kWh (6.0%) compared to Alternative A. The average wholesale capacity rate was
41 estimated to be \$6.06/kW, which is an increase of \$0.35/kW (6.0%) compared to Alternative A.
42

43 This alternative would produce a total benefit of \$46 million over the 20-year LTEMP
44 period compared to Alternative A because of the increase in the economic value of energy
45 produced at Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from
46 the monthly water releases at Glen Canyon Dam.

1 In summary, Alternative C would have the fifth-highest marketable capacity from
2 SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity
3 needed over the 20-year LTEMP period. It also would have the fifth-lowest total cost to meet
4 electric demand over that period. Both the wholesale energy and capacity rates charged by
5 Western would increase compared to Alternative A. It would have the fourth-lowest change in
6 both average retail electric rate and average monthly residential electricity bill in the year of
7 maximum rate impact. It would have the second-largest increase in value of generation at
8 Hoover Dam compared to Alternative A.

11 **4.13.3.4 Alternative D (Preferred Alternative)**

13 Average annual daily generation at Glen Canyon Dam would be 11,477 MWh under
14 representative hydrological conditions. Average daily generation would range from 9,392 MWh
15 in February to 14,051 MWh in July, before falling to 10,381 MWh in October, and then
16 increasing to 11,052 MWh in November (Figure 4.13-2). The value of electricity generated by
17 Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be
18 \$2,613 million, a decrease of \$49 million, or 1.8%, compared to Alternative A. SLCA/IP
19 marketable capacity would be 687.6 MW at the 90% exceedance level, which is a 49.6 MW, or
20 6.7%, decrease compared to Alternative A. There would therefore be slight decreases in average
21 annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable
22 capacity under Alternative D compared to Alternative A.

24 Forecasted increases in electricity demand in the service territories of Western's customer
25 utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity
26 built under Alternative D over the 20-year LTEMP period. An additional gas turbine is built
27 during the LTEMP period compared to Alternative A. Assuming representative hydrological
28 conditions, the total cost (including capital, fixed, and variable costs) to meet system electric
29 demand under Alternative D would be just over \$36.3 billion.

31 Because of the additional gas turbine the average retail electric rate would increase about
32 0.39% and the average monthly residential electricity bill would increase by an average of \$0.38.
33 Both metrics are the average in the year of maximum rate impact.

35 The average wholesale energy rate was estimated to be \$13.86/kWh, which is an increase
36 of \$0.4/kWh (3.0%) compared to Alternative A. The average wholesale capacity rate was
37 estimated to be \$5.89/kW, which is an increase of \$0.17/kW (3.0%) compared to Alternative A.

39 This alternative would have a total benefit of \$22 million over the 20-year LTEMP period
40 compared to Alternative A because of the increase in the economic value of energy produced at
41 Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly
42 water releases at Glen Canyon Dam.

44 In summary, Alternative D would have the third-highest marketable capacity from
45 SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity
46 needed over the 20-year LTEMP period. It also has the fourth-lowest total cost to meet electric

1 demand over that period. Both the wholesale energy and capacity rates charged by Western
2 would increase compared to Alternative A. It has the third-lowest change in both average retail
3 electric rate and average monthly residential electricity bill in the year of maximum rate impact.
4 It would have the fifth-largest increase in value of generation at Hoover Dam compared to
5 Alternative A.

6 7 8 **4.13.3.5 Alternative E** 9

10 Average annual daily generation at Glen Canyon Dam would be 11,521 MWh under
11 representative hydrological conditions. Average daily generation would range from 9,858 MWh
12 in February to 14,352 MWh in July, before falling to 10,332 MWh in October, and then
13 increasing to 11,008 MWh in January (Figure 4.13-2). The value of electricity generated by Glen
14 Canyon Dam over the 20-year LTEMP period under representative conditions would be
15 \$2,620 million, a decrease of \$42 million, or 1.6%, compared to Alternative A. SLCA/IP
16 marketable capacity would be 647.0 MW at the 90% exceedance level, which is a 90 MW, or
17 12.2%, decrease compared to Alternative A. There would therefore be slight decreases in
18 average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP
19 marketable capacity under Alternative E compared to Alternative A.
20

21 Forecasted increases in electricity demand in the service territories of Western's customer
22 utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity
23 built under Alternative E over the 20-year LTEMP period. An additional gas turbine is built
24 during the LTEMP period compared to Alternative A. Assuming representative hydrological
25 conditions, the total cost (including capital, fixed, and variable costs) to meet system electric
26 demand under Alternative E would be just over \$36.3 billion.
27

28 Because of the additional gas turbine the average retail electric rate would increase about
29 0.50% and the average monthly residential electricity bill would increase by an average of \$0.47.
30 Both metrics are the average in the year of maximum rate impact.
31

32 The average wholesale energy rate was estimated to be \$13.93/kWh, which is an increase
33 of \$0.47/kWh (3.5%) compared to Alternative A. The average wholesale capacity rate was
34 estimated to be \$5.92/kW, which is an increase of \$0.2/kW (3.5%) compared to Alternative A.
35

36 This alternative would have a total benefit of \$28 million over the 20-year LTEMP period
37 compared to Alternative A because of the increase in the economic value of energy produced at
38 Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly
39 water releases at Glen Canyon Dam.
40

41 In summary, Alternative E would have the fourth-highest marketable capacity from
42 SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity
43 needed over the 20-year LTEMP period. It also would have the third-lowest total cost to meet
44 electric demand over that period. Both the wholesale energy and capacity rates charged by
45 Western would increase compared to Alternative A. It would have the fifth-lowest change in
46 both average retail electric rate and average monthly residential electricity bill in the year of

1 maximum rate impact. It would have the fourth-largest increase in value of generation at Hoover
2 Dam compared to Alternative A.

5 **4.13.3.6 Alternative F**

7 Average annual daily generation at Glen Canyon Dam would be 11,379 MWh under
8 representative hydrological conditions. Average daily generation under representative
9 hydrological conditions would range from 6,918 MWh in January to 19,995 MWh in June,
10 before falling to 7,891 MWh in in October, and then increasing to 9,495 MWh in November and
11 falling to 6,911 MWh in December (Figure 4.13-2). The value of electricity generated by Glen
12 Canyon Dam over the 20-year study period under representative conditions would be
13 \$2,540 million, a decrease of \$122 million, or 4.6%, compared to Alternative A. SLCA/IP
14 marketable capacity would be 423.1 MW at the 90% exceedance level, which is a 314 MW, or
15 42.6%, decrease compared to Alternative A. There would therefore be large decreases in average
16 annual daily generation in summer and winter months that have the highest electricity prices and
17 a large decrease in SLCA/IP marketable capacity under Alternative F compared to Alternative A.

18
19 Forecasted increases in electricity demand in the service territories of Western's customer
20 utilities and the planned retirement of existing powerplants result in 5,280 MW of new capacity
21 built under Alternative F over the 20-year LTEMP period. Two additional gas turbines are built
22 during the LTEMP period compared to Alternative A. Assuming representative hydrological
23 conditions, the total cost (including capital, fixed, and variable costs) to meet system electric
24 demand under Alternative F would be just over \$36.6 billion.

25
26 Because of the two additional gas turbines the average retail electric rate would increase
27 about 1.21% and the average monthly residential electricity bill would increase by an average of
28 \$1.02. Both metrics are the average in the year of maximum rate impact.

29
30 The average wholesale energy rate was estimated to be \$16.27/kWh, which is an increase
31 of \$2.81/kWh (21%) compared to Alternative A. The average wholesale capacity rate was
32 estimated to be \$6.91/kW, which is an increase of \$1.2/kW (21%) compared to Alternative A.

33
34 This alternative would have a total benefit of \$89 million over the 20-year LTEMP period
35 compared to Alternative A because of the increase in the economic value of energy produced at
36 Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly
37 water releases at Glen Canyon Dam.

38
39 In summary, the operating constraints of Alternative F would require a steady flow from
40 Glen Canyon Dam every month of the year. This alternative would have the lowest marketable
41 capacity (or the seventh highest) from SLCA/IP of all alternatives and the most new capacity
42 needed over the 20-year LTEMP period. It also would have the highest total cost to meet electric
43 demand over that period. Both the wholesale energy and capacity rates charged by Western
44 would increase compared to Alternative A; in fact, this alternative would have the largest
45 increase in wholesale rates of all alternatives. It would the highest change in both average retail
46 electric rate and average monthly residential electricity bill in the year of maximum rate impact.

1 It would have the largest increase in value of generation at Hoover Dam compared to
2 Alternative A.

5 **4.13.3.7 Alternative G**

6
7 Average annual daily generation at Glen Canyon Dam would be 11,403 MWh under
8 representative hydrological conditions. Average daily generation under would range from
9 8,932 MWh in February to 13,256 MWh in June, before falling to 8,827 MWh in December
10 (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year
11 LTEMP period under representative conditions would be \$2,556 million, a decrease of
12 \$106 million, or 4.0%, compared to Alternative A. SLCA/IP marketable capacity would be
13 558.2 MW at the 90% exceedance level, which is which is a 179 MW, or 24.3%, decrease
14 compared to Alternative A. There would therefore be slight decreases in average annual daily
15 generation and hydropower value at Glen Canyon Dam and a large decrease in SLCA/IP
16 marketable capacity under Alternative G compared to Alternative A.

17
18 Forecasted increases in electricity demand in the service territories of Western's customer
19 utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity
20 built under Alternative G over the 20-year LTEMP period. An additional gas turbine is built
21 during the LTEMP period compared to Alternative A. Assuming representative hydrological
22 conditions, the total cost (including capital, fixed, and variable costs) to meet system electric
23 demand under Alternative G would be almost \$36.5 billion.

24
25 While the capital and operating costs borne by Western customer utilities to replace
26 generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates
27 charged by customer utilities under Alternative G and, consequently, changes in the electric bills
28 of residential customers, impact on electric bills paid by residential customers of Western's
29 customer utilities would be less than 1%.

30
31 Because of the additional gas turbine the average retail electric rate would increase about
32 0.64% and the average monthly residential electricity bill would increase by an average of \$0.59.
33 Both metrics are the average in the year of maximum rate impact.

34
35 The average wholesale energy rate was estimated to be \$15.65/kWh, which is an increase
36 of \$2.19/kWh (16%) compared to Alternative A. The average wholesale capacity rate was
37 estimated to be \$6.67/kW, which is an increase of \$0.95/kW (17%) compared to Alternative A.

38
39 This alternative would have a total benefit of \$30 million over the 20-year LTEMP period
40 compared to Alternative A because of the increase in the economic value of energy produced at
41 Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly
42 water releases at Glen Canyon Dam.

43
44 In summary, the operating constraints of Alternative G would require a steady flow from
45 Glen Canyon Dam every month of the year. This alternative would have the sixth-highest
46 marketable capacity from SLCA/IP of all alternatives (the second lowest after Alternative F) and

1 would be tied for the third smallest amount of new capacity needed over the 20-year LTEMP
2 period. It also would have the sixth-lowest total cost to meet electric demand over that period.
3 Both the wholesale energy and capacity rates charged by Western would increase compared to
4 Alternative A; in fact, this alternative would have the second-largest increase in wholesale rates
5 of all alternatives. It would have the sixth-lowest change in both average retail electric rate and
6 average monthly residential electricity bill in the year of maximum rate impact. It would have the
7 second-largest increase in value of generation at Hoover Dam compared to Alternative A.
8
9

10 **4.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE**

11
12 This section describes the potential
13 impacts of changes in dam operations on the
14 recreational use values and nonuse values placed
15 on recreational resources by individuals that visit,
16 or may never visit, Lake Powell, Lake Mead, and
17 the Grand Canyon. It also describes the potential
18 regional economic impacts of changes in
19 recreational visitation in a six-county region, and
20 the potential impacts on low-income and
21 minority populations in an 11-county region in
22 the vicinity of the lakes and river corridor, and in
23 eastern Arizona and northwestern New Mexico.
24 The section also describes the regional economic
25 impacts of changes in customer utility electricity
26 bills and of expansion in electricity generation
27 capacity that would occur as a result of changes
28 in dam operations, as well as the potential
29 impacts of changes in utility bills on low-income
30 and minority populations, including tribal
31 populations, in the seven-state region in which power generated at the Glen Canyon powerplant
32 is marketed.
33
34

Issue: How do alternatives affect
socioeconomics and environmental justice?

Impact Indicators:

- Recreational use values associated with current and potential levels of visitation
- Nonuse (or passive use) economic value associated with the preferences of nonusers
- Employment and income impacts resulting from changes in recreational visitation, customer utility electricity generation capacity expenditures, and residential electricity bill expenditures
- High, adverse, and disproportionate impacts of changes in dam operations on low-income and minority populations

35 **4.14.1 Analysis Methods**

36
37 This section describes the methods used to estimate changes in recreational use values
38 and non-use (or passive use) economic value that would result from changes in dam operations;
39 the methods used to estimate the economic impacts of change in recreational visitation, customer
40 utility electricity generation capacity expenditures, and residential electricity bill expenditures;
41 and methods used to estimate the impacts of changes in dam operations on low-income and
42 minority populations.
43
44

1 **4.14.1.1 Recreational Use Values**
2

3 The economic significance of recreational resources on the Colorado River can be
4 measured both in terms of economic welfare, or consumer surplus, which is the amount of value
5 a consumer of a good or service receives over and above that which would be paid for the good
6 or service in the marketplace. However, as recreational activities are often not a market good, the
7 characteristics of the demand for recreational resources cannot be based on the demand for
8 recreational resources in the marketplace. Accordingly, consumer surplus is often referred to as
9 *non-market value*, which includes both use value and non-use value (also called passive use
10 value).

11
12 Estimation of recreational use values associated with potential changes in recreational
13 resources under each of the alternatives relies on the benefits transfer method. This method
14 involves the application of existing recreational use value estimates for a particular time period,
15 site, level of resource quality, or combination thereof to a situation for which data are not
16 available. The traditional benefits transfer approach to valuing recreation has been to employ
17 existing use values studies conducted at an existing site, adjusting estimates to account for
18 inflation. Transferring use value estimates from older studies rely on finding a study area with
19 the same recreation activity in a similar geographic area as the study site, meaning that the
20 preferred approach is to employ statistical recreation models developed for a study site; such
21 models are used in conjunction with coefficients from an existing site to estimate recreation
22 visitation and/or value at the study site, allowing the model transfer technique to improve the
23 validity of the results compared to the use value transfer approach.

24
25 Because statistical models have been developed for estimating recreation value per trip
26 for two of the three river reaches in the LTEMP study area—Glen Canyon and Upper Grand
27 Canyon—and models estimating recreation use have been developed for Lake Powell and Lake
28 Mead, while other studies have estimated values per trip for recreation use of Lake Powell and
29 Lake Mead, the benefits transfer methods provides a useful and reliable approach to estimating
30 river use values and lake visitation.

31
32 Visitation levels at the reservoirs were estimated using Neher et al. (2013) and then
33 evaluated using the approach described in Gaston et al. (2014). The net economic value of
34 recreation was then estimated for Lake Powell and Lake Mead, using the Lake_Full program; the
35 GCRc_Full program was used to estimate the economic value for recreation on the three
36 reaches of the Colorado River—Glen Canyon (from Glen Canyon Dam to Lees Ferry at RM 0),
37 Upper Grand Canyon (from Lees Ferry to Diamond Creek at RM 225), and Lower Grand
38 Canyon (from Diamond Creek to Lake Mead). These programs and the benefits transfer method
39 are described in Appendix L. A review of use value estimates associated with Lake Powell, Glen
40 Canyon, Upper Grand Canyon, Lower Grand Canyon, and Lake Mead can be found in
41 Gaston et al. (2014).

42
43 In addition to use values, there may also be significant non-use values associated with
44 lake and river resources in the Grand Canyon. A review of non-use valuation studies is provided
45 in Section L.1.2 of Appendix L. The NPS is conducting a survey to determine non-use values
46 associated with recreational resources along the Colorado River Corridor located in the Upper

1 and Lower Grand Canyon. The proposed survey uses a stated choice method (conjoint analysis)
2 to estimate changes in passive use values associated with the impacts on riparian areas occurring
3 under each alternative. The survey will be conducted by the University of Montana and will be
4 administered to households selected from two samples, a national sample including all U.S.
5 households, and a regional sample consisting of households within the Glen Canyon Dam region
6 receiving power from Western, including all utilities receiving power from the Glen Canyon
7 Dam. More information on the proposed survey can be found in Appendix L. The results of this
8 survey were not available for this DEIS, but they may be available for inclusion in the final EIS.

9 10 11 **4.14.1.2 Recreational Economic Impacts** 12

13 The economic impacts of changes in recreational activity under each alternative are
14 estimated using changes in visitor expenditures associated with various types of recreational
15 activities, including angling, rafting, and boating, as well as spending on food and beverages,
16 restaurants, fishing and boating equipment, gasoline for vehicles and boats, camping fees or
17 motel expenses, guide services, and fishing license fees. Impacts occurring under each
18 alternative are estimated for the six-county region in which the majority of recreational
19 expenditures are likely to occur, and includes Coconino County and Mohave County in Arizona,
20 and Garfield County, Kane County, San Juan County, and Washington County in Utah.
21 Although a large number of visitors to Lake Mead come from the western side of the Colorado
22 River in Clark County, Nevada, their share of expenditures on lake recreation in Clark County is
23 not known. Expenditures are therefore assumed to occur in the six counties included in the
24 analysis. Although the addition of Clark County to the analysis would likely produce slightly
25 larger lake recreation employment and income impacts under each of the alternatives, it would
26 not affect relative differences among the alternatives. Economic impacts include both direct and
27 secondary effects of changes in expenditures that may occur on employment and income, and
28 were estimated using the IMPLAN analysis tool (IMPLAN Group, LLC 2014). More
29 information on the data and methods used, and a review of studies of the economic impacts of
30 recreation activities in Glen Canyon, Grand Canyon and the surrounding area can be found in
31 Section L.1.3 of Appendix L.
32
33

34 **4.14.1.3 Electricity Bill Increase and Generation Capacity Expansion Impacts** 35

36 Under each LTEMP alternative, the regional economic impacts of the eight largest
37 Western customer utilities constructing and operating additional powerplants to replace energy
38 and capacity losses from Glen Canyon Dam, and the resulting changes in customer utility
39 electricity prices, were analyzed for the seven-state region in which Western markets power.
40 This region includes Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming.
41 Estimates of the required additional powerplant capacity were taken from the AURORAex
42 model results (see Appendix K), and data on gas powerplant construction and operating
43 expenditures, including materials, equipment, services, direct and indirect labor, by technology,
44 size, and location were taken from the JEDI model (NREL 2015). Data on changes in retail
45 electricity rates charged by the eight largest Western customer utilities, and the resulting changes
46 in residential customer bills, were also included in the analysis (see Appendix K for a description

1 of the retail rate analysis). IMPLAN input-output models (IMPLAN Group, LLC, 2014)
2 (see Section L.1 of Appendix L), were used to estimate the regional economic impacts of
3 additional generating capacity and changes in electricity prices; a separate IMPLAN model
4 represents each of the seven states in the Western power marketing area. Note that the
5 alternatives could affect the seasonal pattern of Lake Mead elevations, and thus power generation
6 and capacity at Hoover Dam. However, such effects at Hoover Dam are anticipated to be
7 relatively small (Section 4.13).

8 9 10 **4.14.1.4 Environmental Justice**

11
12 The analysis of potential environmental justice impacts follows guidelines described in
13 the Council on Environmental Quality's (CEQ's) *Environmental Justice Guidance under the*
14 *National Environmental Policy Act* (CEQ 1997). Because it is likely that under the alternatives
15 considered here the most important impacts resulting from changes in dam operations would be
16 impacts on recreation, the analysis was undertaken for an 11-county region in which the majority
17 of recreational expenditures are like to occur (including Apache County, Coconino County,
18 Mohave County, and Navajo County in Arizona; Cibola County, McKinley County, and San
19 Juan County in New Mexico; and Garfield County, Kane County, San Juan County, and
20 Washington County in Utah). Other potential impacts related to environmental justice include
21 changes in Tribal electricity retail rates, and impacts on Tribal resources and values. Using CEQ
22 guidelines, the impact assessment determined whether each alternative would produce impacts
23 that are high and adverse. If impacts were high and adverse, a determination was made as to
24 whether these impacts would disproportionately affect minority and low-income populations by
25 comparing the proximity of locations where any high and adverse impacts are expected with the
26 location of low-income and minority populations. If impacts are not high and adverse, there can
27 be no disproportionate impacts on minority and low-income populations.

28 29 30 **4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice**

31
32 Table 4.14-1 summarizes the impacts for recreational use values, recreational economic
33 impacts, and environmental justice.

34 35 36 **4.14.2.1 Recreational Use Values**

37
38 Recreational resources in Lake Powell, Lake Mead, and the Grand Canyon produce
39 significant mean annual use values, with recreational activities in Lake Mead and Lake Powell
40 constituting almost 97% of overall use value under each alternative (Table 4.14-2). Use values
41 are presented in terms of net present value, to allow for differences in the distribution of use
42 values between activities over time. Total mean annual use value created by all lake and river
43 recreational activities amounts to \$14,619.8 million under Alternative A (No Action Alternative),
44 values which would decline slightly to between \$14,598.7 million under Alternative F and

1 **TABLE 4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and Environmental Justice^a**

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of socioeconomic impacts	No change from current conditions in use values, or economic activity with no change in lake levels or river conditions.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation compared to Alternative A. Increases in use values and economic activity associated with Lake Mead recreation. Increased economic activity from lower residential electric bills compared to Alternative A.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper and Lower Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper and Lower Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.

4-328

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Use Values^a							
Lake Powell							
	No change from current conditions in use values (\$5,016 million) because no change in water levels	Same as Alternative A	Potential declines in use values of 0.7% (to \$4,983 million) associated with lower water levels	Potential declines in use values of less than 0.4% (to \$4,997 million) associated with lower water levels	Potential declines in use values of less than 0.5% (to \$4,990 million) associated with lower water levels	Potential declines in use values of 1.1% (to \$4,961 million) associated with lower water levels	Potential declines in use values of 0.4% (to \$4,997 million) associated with lower water levels
Glen Canyon							
	No change from current conditions in use values (\$68.8 million) with no changes in river conditions	Potential decline in use values for angling of 3.4% (to \$19.4 million) and no change in day-use rafting (\$48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 6.2% (to \$18.9 million) and no change in day-use rafting (\$48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 4.7% (to \$19.2 million) and no change in day-use rafting (\$48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 3.4% (to \$19.4 million) and no change in day-use rafting (\$48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 13.3% (to \$17.4 million) and no change in day-use rafting (\$48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 6.2% (to \$18.9 million) and no change in day-use rafting (\$48.7 million) associated with changes in river conditions
Upper Grand Canyon							
	No change from current conditions in use values (\$355.8 million) with no changes in river conditions	Potential decline in use values for private whitewater boating of 3.5% (to \$66.5 million) and commercial whitewater boating of 5.8% (to \$270.2 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 1.5% (to \$67.9 million) and commercial boating of 9.0%, (to \$261.2 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 1.3% (to \$68.0 million) and commercial boating of 11.3%, (to \$254.4 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 2.3% (to \$67.4 million) and commercial boating of 12.9%, (to \$249.9 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 0.4% (to \$69.2 million) and decline for commercial boating of 2.3%, (to \$280.2 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 0.6% (to \$68.5 million) and commercial boating of 13.7%, (to \$247.6 million) associated with changes in river conditions

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Use Values^a (Cont.)							
Lower Grand Canyon							
	No change from current conditions in use values (\$64.8 million) with no changes in river conditions	Potential decline in use values for private whitewater boating of 2.0%, (to \$3.6 million) for commercial 1-day boating of 4.6% (to \$44.0 million); for overnight trips of 5.2% (to \$0.52 million); no change for commercial flat-water boating (\$14.5 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 3.4% (to \$3.6 million), for commercial 1-day boating of 9.6% (to \$41.7 million), for overnight trips of 11.5% (to \$0.49 million); no change for commercial flat-water boating (\$14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 1.9% (to \$3.8 million), decrease for commercial 1-day boating of 8.1% (\$42.3 million), decrease for overnight trips of 11.7% (to \$0.48 million); no change for commercial flat-water boating (\$14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 0.6% (to \$3.7 million), decrease for commercial 1-day boating of 10.0% (to \$41.5 million), decrease for overnight trips of 14.0% (to \$0.47 million); no change for commercial flat-water boating (\$14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 13.3% (to \$4.2 million), decrease for commercial 1-day boating of 1.2% (to \$45.5 million), decrease for overnight trips of 8.9% (\$0.46 million); no change for commercial flat-water boating (\$14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 6.8% (to \$3.9 million), decrease for commercial 1-day boating of 8.0% (to \$42.4 million); decrease for overnight trips of 13.2% (to \$0.42 million); no change for commercial flat-water boating (\$14.5 million) associated with changes in river conditions
Lake Mead							
	No changes from current conditions in use values (\$9,114.5 million) with no change in water levels	Potential decrease in use values of 0.002% (to \$9,114.3 million) associated with higher water levels	Potential increase in use values of 0.3% (to \$9,145.2 million) associated with higher water levels	Potential increases in use values of 0.3% (to \$9,139.7 million) associated with higher water levels	Potential increases in use values of 0.3% (to \$9,143.5 million) associated with higher water levels	Potential increases in use values of 0.5% (to \$9,157.5 million) associated with higher water levels	Potential increases in use values of 0.3% (to 9,143.3 million) associated with higher water levels

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Economic Impacts^b</i>							
Lake Powell	No change in direct and indirect employment (2,444 jobs) and income (\$99.7 million)	Same as Alternative A	Declines in direct and indirect employment (to 2,430 jobs) and income (to \$99.1 million) of 0.6%	Declines in direct and indirect employment (to 2,435 jobs) and income (to \$99.3 million) of 0.4%	Declines in direct and indirect employment (to 2,433 jobs) and income (to \$99.2 million) of 0.5%	Declines in direct and indirect employment (to 2,418 jobs) and income (to \$98.6 million) of 1.1%	Declines in direct and indirect employment (to 2,435 jobs) and income (\$99.3 million) of 0.4%
Glen Canyon, Upper, and Lower Grand Canyon	No change in direct and indirect employment (156 jobs) and income (\$3.6 million) associated with any river-based recreational activities	Same as Alternative A	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities
Lake Mead	No change in direct and indirect employment (5,099 jobs) and income (\$208.0 million)	Same as Alternative A	Increases in direct and indirect employment (to 5,116 jobs) and income (to \$208.6 million) of 0.3%	Increases in direct and indirect employment (to 5,114 jobs) and income (to \$208.6 million) of 0.3%	Increases in direct and indirect employment (to 5,115 jobs) and income (to \$208.6 million) of 0.3%	Increases in direct and indirect employment (to 5,124 jobs) and income (to \$209.0 million) of 0.5%	Increases in direct and indirect employment (to 5,115 jobs) and income (to \$208.6 million) of 0.3%

4-331

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Economic Impacts^b (Cont.)</i>							
Seven-State Region							
	No additional generation capacity construction and operation beyond existing capacity expansion plans, which would create 9,519 jobs and \$841.7 million in income during construction and 1,019 jobs and \$69.4 million in income during operation. No change in Western customer utility electricity rates.	No increases in Western customer utility generation capacity construction and operation direct and indirect employment and income impacts compared to Alternative A. Negligible decreases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 10,286 jobs) and income (to \$909.6 million) of 8.1% compared to Alternative A, and increases in operations employment (to 1,114 jobs) and income (to \$75.7 million) of 9.3% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to \$875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to \$72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice							
Overall summary of environmental justice impacts	No change from current conditions. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in up to an average of 3.0 years and 0.4 years, 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 up to an average of 6.5 years and 2.8 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 up to an average of 11.0 years and 2.9 years, respectively, of LTEMP period; financial impacts related to electricity sales would be similar to those under Alternative C. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in up to an average of 2.6 years and 1.7 years, respectively, of LTEMP period; financial impacts related to electricity sales would be similar to those under Alternative C. 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 an average of 11.0 years and 3.1 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as \$1.34/MWh) than those on non-Tribal customers, and would be greater (as much as \$2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.
Tribal commercial and flat-water boating river boat rentals	No impacts expected with no changes in river visitation	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Environmental Justice (Cont.)</i>							
Tribal retailing in vicinity of GCNRA and GCNP	No impacts expected with no changes in river visitation	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Tribal marina operators	No impacts expected	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Some impacts expected; decrease of 1.1% in visitation	Same as Alternative A
Access or damage to culturally important plants and resources	Negligible impacts	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Some damage and reduced access to resources; increase in time off river	Same as Alternative A
Effects on Tribal values associated with TMFs and mechanical extraction of trout in proximity to sacred places of emergence	Negligible impacts, with no TMFs and infrequent trout removal actions (average 0.1 years of LTEMP period)	TMFs and mechanical removal triggered in up to an average of 3.0 years and 0.4 years, respectively, of LTEMP period	TMFs and mechanical removal triggered in up to an average of 6.5 years and 2.8 years, respectively of LTEMP period	TMFs and mechanical removal triggered in up to an average of 11.0 years and 2.9 years, respectively, of LTEMP period	TMFs and mechanical removal triggered in up to an average of 2.6 years and 1.7 years, respectively, of LTEMP period	No impact; TMFs and mechanical removal not allowed under this alternative	Highest impact of all alternatives; TMFs and mechanical removal triggered in an average of 11.0 years and 3.1 years, respectively, of LTEMP period

4-334

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
<i>Environmental Justice (Cont.)</i>							
Financial impacts on Tribes related to electricity sales	No impacts expected	Impacts would be similar to those on non-Tribal customers and those under Alternative A	Impacts on Tribes would be slightly higher (<\$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts on Tribes would be similar to those under Alternative C.	Impacts on Tribes would be similar to those under Alternative C.	Impacts would be slightly higher (<\$1.00/MWh) from those on non-Tribal customers, and would be greater (as much as \$3.26/MWh) than those under Alternative A	Impacts would be slightly higher (as much as \$1.34/MWh) than those on non-Tribal customers, and would be greater (as much as \$2.84/MWh) than those under Alternative A

^a Use values for alternatives are presented in Table 4.14-2.

^b Employment and income values associated with recreational expenditures are presented in Tables 4.14-4 and 4.14-5, respectively. Employment and income associated with generation capacity are presented in Table 4.14-6, and residential electricity bills are presented in Table 4.14-7.

1 **TABLE 4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP**
 2 **Alternatives^a**

Location and Activity	Mean Annual Net Economic Value (\$ Million Net Present Value, 2015) for each Alternative						
	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Lake Powell							
General recreation	5,016.0	5,016.0	4,983.3	4,996.6	4,990.1	4,961.0	4,997.1
Glen Canyon							
Angling	20.1	19.4	18.9	19.2	19.4	17.4	18.9
Day-use rafting	48.7	48.7	48.7	48.7	48.7	48.7	48.7
Upper Grand Canyon							
Private whitewater boating	68.9	66.5	67.9	68.0	67.4	69.2	68.5
Commercial whitewater boating	286.9	270.2	261.2	254.4	249.9	280.2	247.6
Lower Grand Canyon							
Private whitewater boating	3.7	3.6	3.6	3.8	3.7	4.2	3.9
Commercial whitewater boating, 1-day trips	46.1	44.0	41.7	42.3	41.5	45.5	42.4
Commercial whitewater boating, overnight trips	0.55	0.52	0.49	0.48	0.47	0.46	0.42
Commercial flat-water boating	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Lake Mead							
General recreation	9,114.5	9,114.3	9,145.2	9,139.7	9,143.5	9,157.5	9,143.3
All activities	14,619.8	14,598.0	14,585.3	14,587.6	14,579.1	14,598.7	14,585.3

^a Use values are based on historical direct natural flow hydrology, weighted by sediment flow condition.

Source: Gaston et al. (2014).

1 \$14,579.1 million under Alternative E, the latter of which is a decline of 0.3% compared to
2 Alternative A.

3
4 Mean annual use values for general recreation in Lake Powell would fall slightly from
5 \$5,016 million under Alternative A to between \$4,997.1 million under Alternative G and
6 \$4,961.0 million under Alternative F the latter of which represents a decline of 1.1%. Potential
7 declines in use values under each alternative would come primarily as a result of lower reservoir
8 water levels, which would mean exposed beaches and mudflats, reducing the quality of the
9 recreational experience. There would be no change in use values associated with Alternative B
10 compared to Alternative A. For Lake Mead, general recreation use values would increase
11 slightly, from \$9,114.5 million under Alternative A to between \$9,139.7 million under
12 Alternative D to \$9,157.5 million under Alternative F, the latter of which is an increase of 0.5%.
13 Higher use values would primarily result from higher reservoir water levels covering previously
14 exposed mudflats and beaches, improving the quality of the recreational experience. There would
15 be a slight decrease in use values associated with Alternative B compared to Alternative A.
16

17 Although river-based recreation activities produce less mean annual use value than lake-
18 based activities, there would be more variation among alternatives. Differences between each
19 alternative and Alternative A, where high flow experiments are restricted, are primarily due to
20 the extent to which larger fluctuations in flow associated with each alternative are shifted to
21 seasons of the year that are more popular with visitors.
22

23 Angling use values in Glen Canyon would decline from \$20.1 million under
24 Alternative A to between \$19.4 million under Alternative E to \$17.4 million under Alternative F, the
25 latter representing a decline of 13.3%. Use values associated with commercial whitewater
26 boating in the Upper Grand Canyon would fall from \$286.9 million under Alternative A to
27 between \$280.2 million under Alternative F and \$247.6 million under Alternative G, the latter
28 representing a 13.7% decline. Mean annual use value generated by 1-day commercial whitewater
29 boating trips in the Lower Grand Canyon would fall from \$46.1 million under Alternative A to
30 between \$45.5 million under Alternative F and \$41.5 million under Alternative E, the latter of
31 which represents a decline of 10.0%.
32

33 Private whitewater boating in the Upper Grand Canyon produces \$68.9 million in use
34 values under Alternative A, values that would increase to \$69.2 million under Alternatives F, an
35 increase of 0.4%, and fall to between \$68.5 million under Alternative G and \$66.5 million under
36 Alternative B, a decrease of 3.5%. Private whitewater boating in the Lower Grand Canyon would
37 decrease from \$3.7 million under Alternative A to \$3.6 million for Alternative B and C, and
38 increase to between \$3.7 million under Alternative E, and \$4.2 million under Alternative F, an
39 increase of 13.3%,
40

41 Day-use rafting in Glen Canyon would generate \$48.7 million in use value under each of
42 the alternatives, commercial boating overnight trips would produce \$0.5 million under each
43 alternative, while commercial flat-water boating in the Lower Grand Canyon would produce
44 \$14.5 million under each alternative. Use values for either activity would not change under any
45 of the alternatives, because demand for these activities would not be affected by river levels or
46 fluctuations in river flow.

1 With the exception of changes in use value associated with commercial whitewater
2 overnight boating trips and commercial flat-water boating in the Lower Grand Canyon, changes
3 in use value for all other forms of river recreation were statistically significant at the 90%
4 confidence level under each alternative, while changes in use value associated with lake
5 recreation were not statistically significant under any of the alternatives.
6
7

8 **4.14.2.2 Recreational Economic Impacts** 9

10 The regional economic impacts of recreation in Lake Powell, Lake Mead, and the Grand
11 Canyon are closely tied to visitation levels for each recreational activity. By far the most
12 significant recreational resource is Lake Mead, which drew almost 6 million individual trips in
13 2012, 72.0% of the total number of trips to these areas (Table 4.14-3). Lake Powell drew
14 1.9 million trips, or 23.0% of the total, while there were 0.2 million individual Grand Canyon
15 river trips in 2012 (2.5% of the total). Of the river-based recreational activities, commercial flat-
16 water boating in the Lower Grand Canyon, below Diamond Creek, drew the largest number of
17 individual trips (95,520 individual trips, or 46.0% of the total number of individual river trips),
18 followed by day-use rafting in Glen Canyon (53,578 individual trips, 25.8% of the total) and
19 1-day white water boating below Diamond Creek (28,748 individual trips, 13.8% of the total).
20 Commercial whitewater boating in the Upper Grand Canyon drew 17,384 individual trips, or
21 8.4% of total river trips.
22

23 Recreational expenditures by visitors to Lake Powell and Lake Mead, and to the Upper
24 and Lower Grand Canyon, create substantial employment and income in the six-county area in
25 Arizona and Utah (Tables 4.14-4 and 4.14-5). Boating in Lake Mead currently produces
26 5,099 total (direct and indirect) jobs and \$208 million in total income (direct and indirect)
27 annually; boating on Lake Powell produces 2,444 total jobs and \$99.7 million in income. Over
28 the 20-year LTEMP period, annual direct and indirect economic activity would fall to between
29 2,435 jobs and \$99.3 million in income for Alternative G and 2,418 jobs and \$98.6 million in
30 income for Alternative F, for Lake Powell, with increases of between 5,115 jobs and
31 \$208.6 million in income for Alternative G, and 5,124 jobs and \$209.0 million in income for
32 Alternative F for Lake Mead. Changes in employment under Alternative F resulting from
33 changes in recreation at Lake Powell would represent a decrease of 1.1% in compared to
34 Alternative A, and an increase of 0.5% under Alternative F at Lake Mead. There would be no
35 change in recreational economic impacts associated with Alternative B compared to
36 Alternative A.
37

38 Because current NPS regulations restrict the number of river boating trips that can be
39 taken, with a long waiting list for private boating permits and a large number of commercial
40 passengers who cannot be accommodated due to these restrictions (Gaston et al. 2014), the
41 analysis assumes that the number of angling and whitewater boating trips would not change as a
42 result of any of the alternatives, meaning that the regional economic impacts for river recreation
43 under each of the alternatives would be the same as for Alternative A. The largest river
44 recreation impacts are from 1-day commercial whitewater boating trips below Diamond Creek,
45 which produces 61 jobs annually and \$1.4 million in income, and commercial whitewater trips in
46 the Upper Grand Canyon (37 jobs and \$0.8 million in income). Angling (19 jobs and

1 **TABLE 4.14-3 Recreational Visitation by Activity in Lake Powell, Upper**
 2 **and Lower Grand Canyon, and Lake Mead, 2012**

Location	Activity	Number of Annual Individual Trips
Lake Powell	General recreation	1,914,768
Glen Canyon	Angling	4,925
	Day-use rafting	53,578
Upper Grand Canyon	Private white water boating	5,978
	Commercial white water boating	17,384
Lower Grand Canyon	Private white water boating	1,445
	Commercial white water boating, one-day trips	28,748
	Commercial white water boating, overnight trips	100
	Commercial flat-water boating	95,520
Lake Mead	General recreation	5,991,767
Total	All activities	8,114,213

Source: Gaston et al. (2014).

3
 4
 5 **TABLE 4.14-4 Mean Annual Employment Associated with Recreational Expenditures**
 6 **under LTEMP Alternatives**

Location and Activity	Annual Employment (Number of Full-Time Equivalent Jobs ^a) under LTEMP Alternatives						
	A	B	C	D	E	F	G
Lake Powell							
General Recreation	2,444	2,444	2,430	2,435	2,433	2,418	2,435
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	156	156	156	156	156	156	156
Lake Mead							
General Recreation	5,099	5,099	5,116	5,114	5,115	5,124	5,115
Total							
All Activities	7,699	7,699	7,700	7,704	7,702	7,697	7,706

^a To accurately estimate employment, which may include part-time or overtime working, full-time equivalent (FTE) jobs are used. These are the total number of hours worked in a particular activity divided by the number of regular working hours in a year.

7 Source: IMPLAN Group, LLC (2014).

1 **TABLE 4.14-5 Mean Annual Income Associated with Recreational Expenditures**
 2 **under LTEMP Alternatives**

Location and Activity	Annual Income (\$million, 2013) under LTEMP Alternatives						
	A	B	C	D	E	F	G
Lake Powell							
General Recreation	99.7	99.7	99.1	99.3	99.2	98.6	99.3
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Lake Mead							
General Recreation	208.0	208.0	208.6	208.6	208.6	209.0	208.6
Total							
All Activities	311.3	311.3	311.3	311.5	311.4	311.2	311.6

Source: IMPLAN Group, LLC (2014).

3
 4
 5 \$0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water boating)
 6 (19 jobs and \$0.4 million in income) below Diamond Creek would produce smaller impacts. A
 7 total of 156 jobs and \$3.6 million in income are currently produced annually across all river
 8 recreational activities under Alternative A, with the same annual impacts expected under each
 9 alternative.

10
 11
 12 **4.14.2.3 Customer Utility Electricity Generation Capacity and Residential Rate**
 13 **Increase Impacts**

14
 15 Although there would be no change in Glen Canyon Dam capacity under Alternative A,
 16 forecasted increases in the demand for electricity and the planned retirement of existing
 17 powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would
 18 be built by the eight largest Western customer utilities under Alternative A over the 20-year
 19 study period. Under Alternative B, 4,820 MW of additional capacity would also be added, while
 20 a reduction in available generating capacity at Glen Canyon Dam under Alternatives C, D, E,
 21 and G would mean that alternative generating capacity would be required by Western customer
 22 utilities to replace lost hydropower capacity. An additional 5,050 MW would be required under
 23 Alternatives C, D, E, and G (an increase of 4.8% compared to Alternative A), with 5,280 MW
 24 needed under Alternative F (an increase of 9.5%) (see Section 4.13.2.3).

25
 26 Using estimated capital and operating costs associated with providing additional capacity
 27 under each alternative for the eight largest Western customer utilities, the economic impacts of
 28 construction and operation of additional capacity are shown in Table 4.14-6. Under
 29 Alternative A, powerplant construction would produce an estimated 9,519 total (direct and

1 **TABLE 4.14-6 Seven-State Economic Impacts^a under LTEMP Alternatives of**
 2 **Additional Generating Capacity for the Eight Largest Customer Utilities, 2015–2033**

Parameter	Alternative						
	A	B	C	D	E	F	G
Construction							
Employment (FTEs)	9,519	9,519	9,895	9,895	9,895	10,286	9,895
Earnings (\$Million 2015)	841.7	841.7	875.3	875.3	875.3	909.6	875.3
Operations							
Employment (FTEs)	1,019	1,019	1,065	1,065	1,065	1,114	1,065
Earnings (\$Million 2015)	69.4	69.4	72.5	72.5	72.5	75.7	72.5

^a Impacts assume average hydrological conditions, and that powerplants would use advanced oil/gas combined cycle or advanced combustion turbine technology. Construction impacts are total impacts over a 3-year construction period; operations impacts are average annual impacts.

Source: IMPLAN Group, LLC (2014).

3
 4
 5 indirect) jobs in the seven-state region, and \$841.7 million in earnings. Operation of new
 6 powerplants under Alternative A would create 1,019 total jobs and \$69.4 million in annual
 7 earnings. Alternative B would also require the same capacity as Alternative A, with 9,519 jobs
 8 and \$841.7 million in earnings created directly and indirectly in the seven states. Operations
 9 would produce 1,019 total jobs and \$69.4 in earnings per year. Alternatives C, D, E, and G
 10 would require slightly more additional capacity than Alternative A, producing 9,895 total
 11 construction and 1,065 total operations jobs, an increase of 3.9%, \$875.3 million in construction
 12 earnings, and \$72.5 annually during operations. The largest impacts of capacity additions would
 13 be under Alternative F, where 10,286 total jobs, an increase of 8.1%, and \$909.6 million in
 14 earnings would be produced during construction, and 1,114 jobs and \$75.7 million would be
 15 produced annually in earnings during operations. It should be noted that the alternatives could
 16 affect the seasonal pattern of Lake Mead elevations and, thus, power generation and capacity at
 17 Hoover Dam, and the associated impacts described here for Glen Canyon Dam. However, such
 18 effects related to Hoover Dam generation are anticipated to be relatively small (Section 4.13).
 19

20 Costs associated with replacing generation capacity no longer provided at Glen Canyon
 21 Dam would mean changes in retail rates charged by Western customer utilities, and
 22 consequently, changes in the electric bills of residential customers. Although there is
 23 considerable variation in the amount of power sold by Western to customer utilities, ranging
 24 from 0.8% of customer utility power sales with Salt River Project to 23.7% with Navajo Tribal
 25 Utility Authority among the eight largest customer utilities, only 7.3% of power sales for all
 26 eight of the largest customer utilities comes from Western, meaning that the cost of additional
 27 capacity required under each alternative to replace capacity lost at Glen Canyon Dam has only
 28 negligible impacts (average less than 2% in maximum impacts year) on electric bills paid by
 29 residential customers of the eight largest Western customer utilities. Two groups of utilities that

1 are allocated a large fraction of their generation resources from SLCA/IP projects are Tribal
 2 utilities and other small utilities. These groups would be affected more by capacity expansion
 3 differences among alternatives than others; Tribal utilities (Navajo and Cocopah) would
 4 experience up to a 2.8% increase in retail rates, while small utilities with the largest impact
 5 would experience up to a 3.1% increase in retail rates (see Appendix K for additional detail).
 6

7 Although the economic impacts of changes in retail electricity rates and the
 8 corresponding impacts on residential customer bills would be dependent on the timing and
 9 magnitude of capacity expansion required under each alternative, changes in customer rates
 10 under each alternative are small. Table 4.14-7 shows the average annual losses in economic
 11 activity in the seven-state region for the eight largest customer utilities. Impact data are based on
 12 the aggregation of bill increases across the eight largest customer utilities, weighting by
 13 individual utility power sales compared to total power sales for all eight utilities. Changes in
 14 retail rates range from a decrease of 0.27%% under Alternative B to an increase of 1.21% under
 15 Alternative F (Table 4.13-1).
 16

17 The impact of these increases on employment and income in the seven-state region would
 18 range from less than 10 total (direct and indirect) jobs lost and \$0.3 million in earnings lost under
 19 Alternative E to 41 jobs and \$1.9 million in earnings lost under Alternative F. A slight decrease
 20 in electric bills under Alternative B would mean small increases in employment (less than 10
 21 jobs) and earnings (an increase of \$0.1 million).
 22
 23

24 **4.14.2.4 Environmental Justice Impacts**
 25

26 Changes in river and lake recreational visitation might disproportionately impact low-
 27 income and minority populations including Tribal communities, both in the counties in the
 28 vicinity of the GCNRA and GCNP, and in the seven-state area in which power from Glen
 29 Canyon Dam is marketed.
 30
 31

32 **TABLE 4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential**
 33 **Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to Alternative A**

Parameter	Alternative					
	B	C	D	E	F	G
Changes to employment (FTE jobs) compared to Alternative A	An increase in up to 10 new jobs	A reduction of 23 jobs	A reduction of 10 jobs	A reduction of 10 jobs	A reduction of 41 jobs	A reduction of 25 jobs
Changes to earnings (\$2015Million) compared to Alternative A	An increase of \$0.1 in earnings	A loss of \$1.0 in earnings	A loss of \$0.4 in earnings	A loss of \$0.3 in earnings	A loss of \$1.9 in earnings	A loss of \$1.2 in earnings

Source: IMPLAN Group, LLC (2014).

1 **Eleven-County Region**
2

3 There were a large number of low-income and minority individuals in the 11-county
4 region as a whole in the 2010 Census, with 38.0% of the population classified as minority, and
5 12.7% classified as low-income using data from the 2008–2012 American Community Survey.
6 However, the number of minority or low-income individuals does not exceed state averages by
7 20 percentage points or more, and does not exceed 50% of the total population in the area. This
8 means that for the 11-county region as a whole, there are no minority or low-income populations
9 based on the 2010 Census, the 2008–2012 American Community Survey data, and CEQ
10 guidelines. The number of minority individuals exceeds the state average by 20 percentage
11 points or more in Apache County, Arizona; McKinley County, New Mexico; and San Juan
12 County, Utah. Minority individuals exceed 50% of the total population in Apache County and
13 Navajo County, Arizona; Cibola County, McKinley County, and San Juan County, New Mexico;
14 and in San Juan County, Utah, indicating that there are minority populations in each of these
15 counties based on county level data in the 2010 Census, the 2008–2012 American Community
16 Survey data, and CEQ guidelines. Because the number of low-income individuals does not
17 exceed the state average by more than 20 percentage points, or does not exceed 50% of the total
18 population in any of the 11 counties, there are no low-income populations based on county-level
19 data in the 11-county region.
20

21 A large number of census block groups in the vicinity of the GCNRA and GCNP with
22 low-income and minority populations could be affected if changes in visitation levels produced
23 impacts that were high and adverse. In Coconino County, Arizona, a number of block groups
24 have populations where the percentage of minorities is more than 20 percentage points higher
25 than the state average. These are located in the eastern part of the county on the Navajo Nation
26 Indian Reservation and Hopi Indian Reservation, in the western part of the county, including the
27 Havasupai Indian Reservation and the Hualapai Indian Reservation, which are also located in
28 one block group in eastern Mohave County, Arizona. One census block group in Page, Arizona,
29 also has a minority population which is more than 50% of the total. There are a number of census
30 block groups in San Juan County, Utah, where more than 50% of the total population is minority.
31 These are located in the southern portion of the county and include the Navajo Nation Indian
32 Reservation and the Ute Mountain Indian Reservation.
33

34 There are a large number of census block groups in the vicinity of GCNRA and GCNP
35 where the percentage of low-income individuals is more than 20 percentage points higher than
36 the state average. These are located in (1) Coconino County, Arizona, on the Navajo Nation
37 Indian Reservation and the Hopi Indian Reservation; (2) Navajo County, Arizona, on the Navajo
38 Nation Indian Reservation, which also contains the Fort Apache Indian Reservation; (3) eastern
39 Mohave County, Arizona, on the Hualapai Indian Reservation; and (4) southeastern and
40 southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute
41 Mountain Indian Reservation. There are also a number of census block groups in the 11-county
42 area where more than 50% of the total population is below the poverty level. These are located in
43 (1) the eastern part of Coconino County, Arizona, on the Navajo Nation Indian Reservation and
44 Hopi Indian Reservation; (2) southwestern San Juan County, Utah, on the Navajo Nation Indian
45 Reservation and the Ute Mountain Indian Reservation; (3) the northern parts of Navajo County

1 and Apache County, Arizona; and (4) southwestern Navajo County on the Fort Apache Indian
2 Reservation.

3
4 Changes to river recreation could impact Tribes in the vicinity of GCNRA and GCNP.
5 Commercial whitewater and flat-water boating below Diamond Creek is important to the
6 Hualapai Tribe, for employment and income, but as Table 4.14-5 shows, there are negligible
7 differences expected among the alternatives. NPS regulates the number of river boating trips that
8 can be taken, with a set number of river trip launches per year, meaning that none of the
9 alternatives are expected to impact overall levels of recreational river visitation. Although
10 differences in time off river for river trips among the alternatives, or differences in stage levels,
11 could change visitation patterns, either of these leading to potential damage and reduced access
12 to culturally important plants and resources, these impacts are expected to be negligible for all
13 alternatives except Alternative F, which may have a slight increase in the potential for effects to
14 cultural sites based on more time off river (see Table 4.14-5). Changes to river stage levels, such
15 as those caused by HFEs, could temporarily restrict Tribal access to culturally important
16 resources, such as springs, minerals, and plants. Similar impacts may also occur if recreational
17 visitors spend more time away from destination campsites with inundation by higher water levels
18 (Section 4.8), but these impacts are expected to be small. Higher water levels may have positive
19 impacts from flushing out springs that have cultural significance to Tribal members, such as
20 Pumpkin Springs (Section 4.9).

21
22 Temporary changes in access to culturally important Tribal resources and other areas of
23 significance to tribes may also impact Tribal members. As described in Section 4.9, for those
24 Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements
25 without which its sacredness would not be complete. The Zuni, in particular, have established a
26 lasting familial relationship with all aquatic life in the Colorado River and the other water
27 sources in the Canyons (Dongoske 2011a). They consider the taking of life through the
28 mechanical removal of trout or TMFs to be offensive, and to have dangerous consequences for
29 the Zuni. The confluence of the Colorado River and the Little Colorado River is considered a
30 sacred area because of its proximity to places identified in traditional Tribal narratives as the
31 locations of the Zuni and the Hopi emergence into this world and other important events. The
32 killing of fish in proximity to sacred places of emergence is considered desecration, and would
33 have an adverse effect on the Grand Canyon as a Zuni Traditional Cultural Property. The Zuni
34 have expressed their view on this subject in Section 3.9.6. As shown in Table 4.14-1, there are
35 differences among alternatives in the frequency of TMFs and mechanical removal of trout;
36 Alternatives A and F would have the fewest of these actions, and Alternatives D and G the most.

37
38 In addition, fluctuations in lake levels could impact Tribes and resources managed by
39 them, such as the Navajo Antelope Point marina operations. As shown in Section 4.8, there are
40 negligible differences among all alternatives for impact to the Antelope Point marina, except
41 under Alternative F, which shows a small difference from Alternative A (1.1%). As presented in
42 Table 4.8-3, impacts on tradespeople making and selling jewelry and souvenirs to the traveling
43 public along various routes in the region, primarily those in the vicinity of GCNRA and GCNP,
44 are likely to be negligible, with no differences between the alternatives.

1 **Seven-State Region**
2

3 A large number of minority and low-income individuals are located in the seven-state
4 region in which electricity from Glen Canyon Dam is marketed. In the region as whole, 35.7% of
5 the population is classified as minority, while 15.1% is classified as low income. However, the
6 number of minority or low-income individuals does not exceed the respective national averages
7 by 20 percentage points or more, and does not exceed 50% of the total population in the area,
8 meaning that for the seven-state region as a whole, there are no minority or low-income
9 populations based on 2010 Census, the 2008–2012 American Community Survey data, and CEQ
10 guidelines. Within one state in the region, New Mexico, 59.5% of the total population is
11 minority, meaning that according to 2010 Census and 2008–2012 American Community Survey
12 data and CEQ guidelines, there is a minority population in the state.
13

14 Although there are no minority populations in any of the seven states except for New
15 Mexico, and no low-income populations, there are a large number of Tribal members in the
16 seven-state area, many of whom reside on Indian Reservations. Many of these individuals have
17 low-income status.
18

19 Tribal members receive a significant portion of their electricity from Western, which
20 currently targets an allocation of 65% of total Tribal electrical use to the 57 Tribes or Tribal
21 entities currently receiving an allocation of power from SLCA/IP; this includes power from Glen
22 Canyon Dam (see Section K.4 in Appendix K). Nine Tribes operate their own electric utilities
23 and receive power directly from Western; the remaining 48 have a benefit crediting arrangement.
24 In a benefit crediting arrangement, the Tribe’s electric service supplier takes delivery of the
25 SLCA/IP allocation and in return gives an economic benefit or a payment to the tribe.
26

27 Tribes may be financially affected in one of three ways by the LTEMP alternatives: (1) a
28 change in the rate they pay for SLCA/IP electric power if they operate their own utility; (2) a
29 change in the payment they receive from their electric service provider if they have a benefit
30 crediting arrangement; or (3) a change in both the payment they receive from their supplier for
31 the benefit crediting arrangement and the electric rate their supplier charges if their supplier also
32 receives an SLCA/IP allocation.
33

34 The benefit credit is computed by taking the difference between the SLCA/IP rate and the
35 supplier rate and multiplying it by the Tribe’s SLCA/IP allocation. Because the SLCA/IP rate is
36 generally lower than the supplier’s rate, the difference between the rates is considered a benefit
37 by the Tribe and is the financial equivalent of a direct delivery of electricity.
38

39 Tribes whose supplier also receives a SLCA/IP allocation have a second financial impact.
40 The retail electricity rate their supplier charges could change as a result of an alternative. The
41 retail rate impact is computed by taking the difference in retail rates between an alternative and
42 Alternative A and multiplying by the total electrical use on the Tribe’s reservation. Therefore,
43 the financial impact on these Tribes is the sum of the Tribal benefit credit and the retail rate
44 impact.
45

1 The financial impact of all alternatives would be relatively small, but the impact on
2 Tribal members would be greater than on non-Tribal residential customers (Table 4.14-8; see
3 Section K.4 in Appendix K for a description of the analysis and results). Differences in impacts
4 on the three groups are as follows:

- 5
6 • Tribal customers receiving power from a non-Tribal utility with an associated
7 benefit credit: Financial impacts (increases in retail rates and reductions in
8 benefit credit) would range from an average increase (compared to
9 Alternative A) of \$0.00/MWh under Alternative B to \$1.63/MWh under
10 Alternative G. Alternatives C, D, E, and F would produce an increase in
11 financial impact of \$0.37, \$0.31, \$0.24, and \$1.53/MWh, respectively. The
12 Tribe with the maximum impact would experience financial impacts of -\$0.05
13 (net benefit), \$0.91, \$0.68, \$0.58, \$3.26, and \$2.84/MWh under
14 Alternatives B, C, D, E, F, and G, respectively.
- 15
16 • Tribal customers that purchase from Tribal-owned utilities: Financial impacts
17 (increases in retail rates) would range from an average increase (compared to
18 Alternative A) of \$0.00/MWh under Alternative B to \$1.72/MWh under
19 Alternative G. Alternatives C, D, E, and F would produce an increase in
20 financial impact of \$0.37, \$0.31, \$0.24, and \$1.53/MWh, respectively. The
21 Tribe with the maximum impact would experience financial impacts of \$0.02,
22 \$0.44, \$0.39, \$0.30, \$2.00, and \$2.37/MWh under Alternatives B, C, D, E, F,
23 and G, respectively.
- 24
25 • Non-Tribal customers: Financial impacts (increases in retail rates) would
26 range from an average increase (compared to Alternative A) of -\$0.02/MWh
27 (net benefit) under Alternative B to a \$0.67/MWh increase under
28 Alternative F. Alternatives C, D, E, and G would produce an increase in
29 financial impact of \$0.22, \$0.15, \$0.13, and \$0.38/MWh, respectively. The
30 Tribe with the maximum impact would experience financial impacts of -\$0.07
31 (net benefit), \$0.62, \$0.41, \$0.38, \$1.86, and \$1.07/MWh under
32 Alternatives B, C, D, E, F, and G, respectively.

33
34 In summary, for the majority of resource areas, impacts on minority and low-income
35 individuals are likely to be negligible. Commercial whitewater and flat-water boating below
36 Diamond Creek is important to the Hualapai Tribe for employment and income, but there are
37 expected to be negligible economic differences expected among the alternatives. Fluctuations in
38 lake levels affecting the Navajo Antelope Point marina operations are expected to be negligible
39 under all alternatives except Alternative F, which shows a small difference from Alternative A.
40 Impacts also are likely to be negligible on tradespeople making and selling jewelry and souvenirs
41 to the traveling public along routes in the vicinity of the Grand Canyon itself, with no differences
42 between the alternatives.

1 **TABLE 4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers**

Parameter	Average Value under Alternative A (\$/MWh)	Change from Alternative A					
		Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
<i>Tribal Customers with Benefit Credit (48 Utilities)</i>							
Average Retail Rate (\$/MWh)	91.82	-0.01	0.08	0.05	0.05	0.23	0.13
Average Benefit Credit (\$/MWh)	8.84	-0.01	-0.27	-0.24	-0.18	-1.23	-1.45
Total of Retail and Benefit Impacts (\$/MWh)	82.98	0.00	0.37	0.31	0.24	1.53	1.63
Maximum Impact: Hopi Tribe	72.67	-0.05	0.91	0.68	0.58	3.26	2.84
<i>Tribal Customers without Benefit Credit (nine Utilities)</i>							
Average Retail Rate (\$/MWh)	95.09	0.00	0.40	0.33	0.26	1.63	1.72
Maximum Impact: Ak-Chin Indian Community	83.10	0.02	0.44	0.39	0.30	2.00	2.37
<i>Non-Tribal Customers (142 Utilities)</i>							
Average Retail Rate (\$/MWh)	92.15	-0.02	0.22	0.15	0.13	0.67	0.38
Maximum Impact	73.74	-0.07	0.62	0.41	0.38	1.86	1.07

2
 3
 4 Differences in time off river and differences in stage levels, such as those caused by
 5 inundation during HFEs, could lead to damage and reduced Tribal access to culturally important
 6 plants and resources. However, the impacts are expected to be negligible for all alternatives
 7 except Alternative F, which may lead to a slight increase in impacts on cultural sites.

8
 9 The financial impacts on Tribal members would be greater than those on non-Tribal
 10 residential customers, especially under Alternatives F and G. Financial impacts of other
 11 alternatives are all less than \$1.00/MWh.

12
 13

1 **4.14.3 Alternative-Specific Impacts**
2
3

4 **4.14.3.1 Alternative A (No Action Alternative)**
5

6 Use values associated with recreation in Lake Powell, Lake Mead, and the Upper and
7 Lower Grand Canyon are substantial and current use values would not change under
8 Alternative A. Use values associated with general recreational activities in Lake Mead
9 (\$9,114.4 million) and Lake Powell (\$5,016 million) constitute almost 97% of the value created
10 by lake and river resources in the affected area under Alternative A. Under Alternative A,
11 commercial and private whitewater boating would produce \$286.9 million and \$68.9 million in
12 use value, respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon
13 would produce lower use values.
14

15 Recreational expenditures by visitors to Lake Powell, Lake Mead, and the Upper and
16 Lower Grand Canyon create substantial employment and income in the six-county area in
17 Arizona and Utah. Private boating in Lake Mead and Lake Powell would produce the largest
18 number of jobs and the largest amount of income, amounting to 7,543 jobs and \$307.7 million in
19 income annually over the 20-year LTEMP period.
20

21 The largest river recreation impacts are from 1-day commercial whitewater boating trips
22 below Diamond Creek, which produces 61 jobs and \$1.4 million in income, and commercial
23 whitewater trips in the Upper Grand Canyon (37 jobs and \$0.8 million in income). Angling
24 (19 jobs and \$0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water
25 boating) (19 jobs and \$0.4 million in income) below Diamond Creek would produce smaller
26 impacts.
27

28 A total of 7,699 jobs and \$311.3 million in income would be produced annually across all
29 lake and river recreational activities under Alternative A over the 20-year LTEMP period.
30

31 Although no additional generating capacity would be required under Alternative A as a
32 result of changes in Glen Canyon Dam operations among the eight largest Western customer
33 utilities, forecasted increases in the demand for electricity in the service territories of the eight
34 largest customer utilities and the planned retirement of existing powerplant generating capacity
35 would mean that an estimated 4,820 MW of new capacity would be built under Alternative A
36 over the 20-year LTEMP period. Using estimated capital and operating costs associated with
37 providing additional capacity, powerplant construction would produce 9,519 total (direct and
38 indirect) jobs in the seven-state region, and \$841.7 million in earnings. Operation of new
39 powerplants with Alternative A would create 1,019 total jobs and \$69.4 million in annual
40 earnings associated with new jobs.
41

42 Because there would be no change in Glen Canyon Dam operations as a result of
43 Alternative A, there would be no impact on retail rates charged by the eight largest Western
44 customer utilities or the electric bills paid by their residential customers, or subsequent impacts
45 on employment or income, in the seven-state region.
46

1 In summary, with no change in lake levels or river conditions under Alternative A, there
2 would be no change from current conditions in use values, economic activity, residential
3 electricity bills, or environmental justice.
4

6 **4.14.3.2 Alternative B**

7
8 Under Alternative B, total use values associated with recreation in Lake Mead and the
9 Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while
10 remaining unchanged for Lake Powell (Table 4.14-2). General recreational activities in Lake
11 Mead would produce \$9,114.3 million in use value and \$5,016.0 million at Lake Powell, while
12 commercial and private whitewater boating would produce \$270.2 million (5.8% decrease) and
13 slightly less than \$66.5 million (3.5% decrease), respectively, in the Upper Grand Canyon; other
14 activities in the Lower Grand Canyon would produce lower use values.
15

16 Under Alternative B, recreational expenditures by visitors and the number of jobs and
17 income that would be created would be the same as under Alternative A (Tables 4.14-4 and
18 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of
19 jobs and income, amounting to 7,543 jobs and \$307.7 million in income annually over the
20 20-year LTEMP period. Impacts on river-based recreational activities would be the same as
21 those under Alternative A.
22

23 Because Alternative B would feature the same monthly volumes as Alternative A, there
24 would be no change in use value and economic impact associated with lake-based recreational
25 activities. Changes in use values associated with Glen Canyon angling and Upper and Lower
26 Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would
27 be primarily due to larger fluctuations in flow that would occur in seasons of the year more
28 popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon
29 commercial overnight boating trips, and commercial flat-water boating would not change,
30 because demand for these activities would not be affected by river levels or fluctuations in flow
31 under this alternative. With no changes in visitation for any of the river-based activities, there
32 would be no change in the economic impact of these activities under Alternative B compared to
33 Alternative A.
34

35 Although additional generating capacity would not be necessary under Alternative B as a
36 result of changes in Glen Canyon Dam operations among the eight largest Western customer
37 utilities, forecasted increases in the demand for electricity in the service territories of the eight
38 largest customer utilities and the planned retirement of existing powerplant generating capacity
39 would mean that an estimated 4,820 MW of new capacity would be built under Alternative B
40 over the 20-year LTEMP period, as would be the case for Alternative A. Using estimated capital
41 and operating costs associated with providing additional capacity, powerplant construction
42 would produce 9,519 total (direct and indirect) jobs in the seven-state region, and \$841.7 million
43 in earnings. Operation of new powerplants under Alternative B would create 1,019 total jobs and
44 \$69.4 million in annual earnings associated with new jobs.
45

1 Because there would be slightly more Glen Canyon Dam generation capacity under
2 Alternative B, retail rates charged by the eight largest Western customer utilities and the electric
3 bills paid by their residential customers would fall, meaning the addition of less than 10 total
4 (direct and indirect) jobs and an increase of \$0.1 million in earnings in the seven-state region.
5

6 With no change in river visitation there would be no impacts on Tribal river boat rental
7 operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative B, and the
8 impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or
9 damage to culturally important plants and resources would be negligible, but impacts on Tribal
10 values related to implementation of TMFs and mechanical removal of trout would be adverse.
11 Financial impacts on Tribes related to electricity sales would be similar to those on non-Tribal
12 customers, and those under Alternative A.
13

14 In summary, under Alternative B, there would be a decline in use values associated with
15 Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, Lower
16 Grand Canyon private whitewater boating commercial whitewater 1-day trips, and Lake Mead
17 recreation compared to Alternative A. There would be no change in use values associated with
18 Lake Powell recreation, Glen Canyon day-use rafting, Lower Grand Canyon commercial
19 whitewater boating overnight trips, or commercial flatwater boating. There would also be no
20 change in economic activity associated with Lake Powell and Lake Mead recreation, or river
21 recreation. There would be an increase in economic activity as a result of lower residential
22 electric bills compared to Alternative A.
23
24

25 **4.14.3.3 Alternative C**

26
27 Under Alternative C, total use values associated with recreation in Lake Powell and the
28 Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while
29 increasing for Lake Mead (Table 4.14-2). General recreational activities would produce
30 \$9,145.2 million (0.3% increase) in use value at Lake Mead and \$4,983.3 million
31 (0.7% decrease) at Lake Powell, while commercial and private whitewater boating would
32 produce \$261.2 million (9.0% decrease) and \$67.9 million (1.5% decrease), respectively, in the
33 Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use
34 values.
35

36 Under Alternative C, recreational expenditures by visitors and the number of jobs and
37 income that would be created in the six-county area in Arizona and Utah would be similar to
38 those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake
39 Powell would produce the largest number of jobs and income, amounting to 7,544 jobs and
40 \$307.7 million in income annually over the 20-year LTEMP period, a difference of 0.04%
41 compared to Alternative A. Impacts on river-based recreational activities would be the same as
42 those under Alternative A. A total of 7,700 jobs and \$311.3 million in income would be
43 produced annually across all lake and river recreational activities under Alternative C over the
44 20-year LTEMP period.
45

1 Differences in use value and economic impact associated with lake-based recreational
2 activities under Alternative C compared to Alternative A would result primarily from changes in
3 reservoir water levels, which would mean differences in exposure of beaches and mudflats, and
4 consequently a change in the quality of recreational experience, and reduced visitor spending.
5 Changes in use values associated with Glen Canyon angling and Upper and Lower Grand
6 Canyon private whitewater boating and commercial whitewater boating 1-day trips would be
7 primarily due to the shifting of monthly volumes away from seasons of the year that are more
8 popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon
9 commercial overnight boating trips, and commercial flat-water boating would not change,
10 because demand for these activities would not be affected by river levels or fluctuations in flow
11 under this alternative. With no changes in visitation for any of the river-based activities, there
12 would be no change in the economic impact of these activities under Alternative C compared to
13 Alternative A.

14
15 In addition to changes in generation and marketable capacity resulting from changes in
16 Glen Canyon Dam operations under Alternative C, there would also be forecasted increases in
17 the demand for electricity in the service territories of the eight largest Western customer utilities,
18 and the planned retirement of existing powerplant generating capacity, meaning that an estimated
19 5,050 MW of new capacity would be built under Alternative C over the 20-year LTEMP period.
20 Using estimated capital and operating costs associated with providing additional capacity,
21 powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state
22 region, and \$875.3 million in earnings. Operation of new powerplants under Alternative C would
23 create 1,065 total jobs, a difference of 3.9% compared to Alternative A, and \$72.5 million in
24 annual earnings associated with new jobs.

25
26 Although costs associated with replacing generation capacity no longer provided at Glen
27 Canyon Dam would mean changes in retail rates charged by Western customer utilities, and
28 consequently changes in the electric bills of residential customers, the cost of additional capacity
29 required to replace capacity lost at Glen Canyon Dam under Alternative C would only have
30 negligible impacts on electric bills paid by residential customers of the eight largest Western
31 customer utilities, and would mean the loss of 23 total (direct and indirect) jobs and \$1.0 million
32 in earnings in the seven-state region.

33
34 With no change in river visitation there would be no impacts on Tribal river boat rental
35 operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the
36 impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or
37 damage to culturally important plants and resources would be negligible, but impacts on Tribal
38 values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on
39 Tribes related to electricity sales would be slightly higher (<\$1.00/MWh) than those on non-
40 Tribal customers, and those under Alternative A.

41
42 In summary, under Alternative C there would be a decline in use values associated with
43 Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial
44 whitewater boating, Lower Grand Canyon private whitewater boating, and commercial
45 whitewater 1-day trips compared to Alternative A. There would also be a decline in economic
46 activity associated with Lake Powell recreation. There would be no change in use values

1 associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater
2 boating overnight trips, or commercial flatwater boating. There would also be no change in
3 economic activity associated with river recreation. There would be an increase in use values and
4 economic activity associated with Lake Mead recreation. Increased economic activity would
5 result from customer utility capacity expansion compared to Alternative A, and reduced
6 economic activity would come as a result of higher residential electric bills.
7
8

9 **4.14.3.4 Alternative D (Preferred Alternative)**

10
11 Under Alternative D, total use values associated with recreation in Lake Powell, and the
12 Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while
13 increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would
14 produce \$9,139.7 million (0.3% increase) in use value and \$4,996.6 million (0.4% decrease) at
15 Lake Powell, while commercial and private whitewater boating would produce \$254.4 million
16 (11.3% decrease) \$68.0 million (a 1.3% decrease), respectively, in the Upper Grand Canyon;
17 other activities in the Lower Grand Canyon would produce lower use values.
18

19 Under Alternative D, recreational expenditures by visitors and the number of jobs and
20 income that would be created in the six-county area in Arizona and Utah would be similar to
21 those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake
22 Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and
23 \$307.8 million in income annually over the 20-year study period, a difference of 0.1% compared
24 to Alternative A. Impacts on river-based recreational activities would be the same as those for
25 Alternative A. A total of 7,702 jobs and \$311.4 million in income would be produced annually
26 across all lake and river recreational activities under Alternative D over the 20-year
27 LTEMP period.
28

29 Reductions in use value and economic impact associated with lake-based recreational
30 activities under Alternative D compared to Alternative A would come primarily as a result of
31 changes in reservoir water levels, which would mean differences in exposure of beaches and
32 mudflats, and consequently a change in the quality of recreational experience, as well as reduced
33 visitor spending. Changes in use values associated with Glen Canyon angling and Upper and
34 Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips
35 would be primarily related to the shifting of monthly volumes away from seasons of the year
36 more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon
37 commercial overnight boating trips, and commercial flat-water boating would not change,
38 because demand for these activities would not be affected by river levels or fluctuations in flow
39 under this alternative. With no changes in visitation for any of the river-based activities, there
40 would be no change in the economic impact of these activities under Alternative D compared to
41 Alternative A.
42

43 In addition to changes in generation and marketable capacity resulting from changes in
44 Glen Canyon Dam operations under Alternative D, there would also be forecasted increases in
45 the demand for electricity in the service territories of the eight largest Western customer utilities
46 and the planned retirement of existing powerplant generating capacity, meaning that an estimated

1 5,050 MW of new capacity would be built under Alternative D over the 20-year LTEMP period.
2 Using estimated capital and operating costs associated with providing additional capacity,
3 powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state
4 region, a difference of 3.9% compared to Alternative A, and \$875.3 million in earnings.
5 Operation of new powerplants under Alternative D would create 1,065 total jobs and
6 \$72.5 million in annual earnings associated with new jobs.
7

8 Although costs associated with replacing generation capacity no longer provided at Glen
9 Canyon Dam would mean changes in retail rates charged by Western customer utilities, and
10 consequently changes in the electric bills of residential customers, the cost of additional capacity
11 required to replace capacity lost at Glen Canyon Dam under Alternative D would have impacts
12 on electric bills paid by residential customers of the eight largest Western customer utilities and
13 would mean the loss of less than 10 total (direct and indirect) jobs and \$0.4 million in earnings in
14 the seven-state region.
15

16 With no change in river visitation there would be no impacts on Tribal river boat rental
17 operators or Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the
18 impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or
19 damage to culturally important plants and resources would be negligible, but impacts on Tribal
20 values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on
21 Tribes related to electricity sales would be slightly higher (<\$1.00/MWh) than those on non-
22 Tribal customers, and those under Alternative A.
23

24 In summary, under Alternative D there would be a decline in use values associated with
25 Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial
26 whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to
27 Alternative A. There would also be a decline in economic activity associated with Lake Powell
28 recreation. There would be no change in use values associated with Glen Canyon day-use rafting,
29 Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater
30 boating. There would also be no change in economic activity associated with river recreation.
31 There would be an increase in use values for Lower Grand Canyon private whitewater boating
32 and use values and economic activity associated with Lake Mead recreation. There would be
33 increased economic activity from customer utility capacity expansion compared to Alternative A,
34 and reduced economic activity as a result of higher residential electric bills.
35
36

37 **4.14.3.5 Alternative E** 38

39 Under Alternative E, total use values associated with recreation in Lake Powell and the
40 Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while
41 increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would
42 produce \$9,143.5 million (0.3% increase) in use value and \$4,990.1 million (0.5% decrease) at
43 Lake Powell, while commercial and private whitewater boating would produce \$249.9 million
44 (12.9% decrease) and \$67.4 million (a 2.3% decrease), respectively, in the Upper Grand Canyon;
45 other activities in the Lower Grand Canyon would produce lower use values.
46

1 Under the Alternative E, recreational expenditures by visitors and the number of jobs and
2 income that would be created in the six-county area in Arizona and Utah would be similar to
3 those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake
4 Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and
5 \$307.8 million in income annually over the 20-year study period, a difference of 0.1% compared
6 to Alternative A. Impacts on river-based recreational activities would be the same as those under
7 Alternative A. A total of 7,702 jobs and \$311.4 million in income would be produced annually
8 across all lake and river recreational activities under Alternative E over the 20-year LTEMP
9 period.

10
11 Small reductions in use value and economic impact associated with lake-based
12 recreational activities under Alternative E compared to Alternative A would result primarily
13 from changes in reservoir water levels, which would mean differences in exposure of beaches
14 and mudflats, and consequently a change in the quality of recreational experience and reduced
15 visitor spending. Changes in use values associated with Glen Canyon angling and Upper and
16 Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips
17 would be primarily related to the shifting of monthly volumes away from seasons of the year that
18 are more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand
19 Canyon commercial overnight boating trips, and commercial flat-water boating would not
20 change, because demand for these activities would not be affected by river levels or fluctuations
21 in flow under this alternative. With no changes in visitation for any of the river-based activities,
22 there would be no change in the economic impact of these activities under Alternative E
23 compared to Alternative A.

24
25 In addition to changes in generation and marketable capacity resulting from changes in
26 Glen Canyon Dam operations under Alternative E, there would also be forecasted increases in
27 the demand for electricity in the service territories of the eight largest Western customer utilities
28 and the planned retirement of existing powerplant generating capacity, meaning that an estimated
29 5,050 MW of new capacity would be built under Alternative E over the 20-year LTEMP period.
30 Using estimated capital and operating costs associated with providing additional capacity,
31 powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state
32 region, a difference of 3.9% compared to Alternative A, and \$875.3 million in earnings.
33 Operation of new powerplants under Alternative E would create 1,065 total jobs and
34 \$72.5 million in annual earnings associated with new jobs.

35
36 Although costs associated with replacing generation capacity no longer provided at
37 Glen Canyon Dam would mean changes in retail rates charged by Western customer utilities, and
38 consequently changes in the electric bills of residential customers, the cost of additional capacity
39 required to replace capacity lost at Glen Canyon Dam under Alternative E would only have
40 negligible impacts on electric bills paid by residential customers of the eight largest Western
41 customer utilities, and would mean the loss of less than 10 total (direct and indirect) jobs and
42 \$0.3 million in earnings in the seven-state region.

43
44 With no change in river visitation there would be no impacts on Tribal river boat rental
45 operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative E, and the
46 impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or

1 damage to culturally important plants and resources would be negligible, but impacts on Tribal
2 values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on
3 Tribes related to electricity sales would be slightly higher (<\$1.00/MWh) than those on non-
4 Tribal customers, and those under Alternative A.

5
6 In summary, under Alternative E there would be a decline in use values associated with
7 Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial
8 whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to
9 Alternative A. There would also be a decline in economic activity associated with Lake Powell
10 recreation. There would be no change in use values associated with Glen Canyon day-use rafting,
11 Lower Grand Canyon private whitewater boating, commercial whitewater boating overnight
12 trips, or commercial flatwater boating. There would also be no change in economic activity
13 associated with river recreation. There would be an increase in use values and economic activity
14 associated with Lake Mead recreation. There would be increased economic activity from
15 customer utility capacity expansion compared to Alternative A, and reduced economic activity as
16 a result of higher residential electric bills.

17 18 19 **4.14.3.6 Alternative F**

20
21 Under Alternative F, total use values associated with recreation in Lake Powell, and the
22 Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while
23 increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would
24 produce \$9,157.5 million (0.5% increase) in use value and \$4,961.0 million (1.1% decrease) at
25 Lake Powell, while commercial and private whitewater boating in the Upper Grand Canyon
26 would produce \$280.2 million (2.3% decrease) and \$69.2 million (0.4% increase), respectively;
27 other activities in the Lower Grand Canyon would produce lower use values.

28
29 Under Alternative F, recreational expenditures by visitors and the number of jobs and
30 income that would be created in the six-county area in Arizona and Utah would be similar to
31 those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake
32 Powell would produce the largest number of jobs and income, amounting to 7,542 jobs and
33 \$307.6 million in income annually over the 20-year LTEMP period, a difference of 0.02%
34 compared to Alternative A. Impacts on the various river-based recreational activities would be
35 the same as those under Alternative A. A total of 7,697 jobs and \$311.2 million in income would
36 be produced annually across all lake and river recreational activities under Alternative F over the
37 20-year LTEMP period.

38
39 Small reductions in use value and economic impact associated with lake-based
40 recreational activities under Alternative F compared to Alternative A would come primarily as a
41 result of changes in reservoir water levels, which would mean differences in exposure of beaches
42 and mudflats, and consequently a change in the quality of recreational experience and reduced
43 visitor spending. Changes in use values associated with Glen Canyon angling and Upper and
44 Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips
45 would be primarily related to the large shifts in monthly volumes; although the high volumes of
46 May and June would result in higher use value during those months, the very low flows for much

1 of the rest of the year would result in lower use value at those times. Use values for Glen Canyon
2 day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-
3 water boating would not change, because demand for these activities would not be affected by
4 river levels under this alternative. With no changes in visitation for any of the river-based
5 activities, there would be no change in the economic impact of these activities under
6 Alternative F compared to Alternative A.

7
8 In addition to changes in generation and marketable capacity resulting from changes in
9 Glen Canyon Dam operations under Alternative F, there would also be forecasted increases in
10 the demand for electricity in the service territories of the eight largest Western customer utilities,
11 and the planned retirement of existing powerplant generating capacity, meaning that an estimated
12 5,280 MW of new capacity would be built under Alternative F over the 20-year study period.
13 Using estimated capital and operating costs associated with providing additional capacity,
14 powerplant construction would produce 10,286 total (direct and indirect) jobs in the seven-state
15 region, a difference of 8.1% compared to Alternative A, and \$909.6 million in earnings.
16 Operation of new powerplants under Alternative F would create 1,114 total jobs and
17 \$75.7 million in annual earnings associated with new jobs.

18
19 Although costs associated with replacing generation capacity no longer provided at Glen
20 Canyon Dam would mean changes in retail rates charged by Western customer utilities, and
21 consequently changes in the electric bills of residential customers, the cost of additional capacity
22 required to replace capacity lost at Glen Canyon Dam under Alternative F would only have
23 negligible impacts on electric bills paid by residential customers of the eight largest Western
24 customer utilities, and would mean the loss of 41 total (direct and indirect) jobs and \$1.9 million
25 in earnings in the seven-state region.

26
27 With no change in river visitation there would be no impacts on Tribal river boat rental
28 operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative F,
29 although changes in lake visitation would be sufficient to affect Tribal marina operators. Access
30 or damage to culturally important plants and resources would also be affected under
31 Alternative F. No impacts on Tribal values related to TMFs or mechanical removal of trout
32 would occur because these actions are not allowed under this alternative. Financial impacts on
33 Tribes related to electricity sales would be slightly higher (<\$1.00/MWh) from those on non-
34 Tribal customers, and would be greater (as much as \$3.26/MWh) than those under Alternative A.

35
36 In summary, under Alternative F there would be a decline in use values associated with
37 Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon commercial whitewater
38 boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to
39 Alternative A. There would also be a decline in economic activity associated with Lake Powell
40 recreation. There would be no change in use values associated with Glen Canyon day-use rafting,
41 Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater
42 boating. There would also be no change in economic activity associated with river recreation.
43 There would be an increase in use values in Upper and Lower Grand Canyon private whitewater
44 boating and in use values economic activity associated with Lake Mead recreation. There would
45 be increased economic activity from customer utility capacity expansion compared to
46 Alternative A, and reduced economic activity as a result of higher residential electric bills.

1 **4.14.3.7 Alternative G**
2

3 Under Alternative G, total use values associated with recreation in Lake Powell, and the
4 Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while
5 increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would
6 produce \$9,143.3 million (0.3% increase) in use value and \$4,997.1 million (0.4% decrease) at
7 Lake Powell, while commercial and private whitewater boating would produce \$247.6 million
8 (13.7% decrease) and \$68.5 million (a 0.6% decrease), respectively, in the Upper Grand Canyon;
9 other activities in the Lower Grand Canyon would produce lower use values.

10
11 Under Alternative G, recreational expenditures by visitors and the number of jobs and
12 income that would be created in the six-county area in Arizona and Utah would be similar to
13 those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake
14 Powell would produce the largest number of jobs and income, amounting to 7,550 jobs and
15 \$308.0 million in income annually over the 20-year LTEMP period, a difference of 0.1%
16 compared to Alternative A. Impacts on river-based recreational activities would be the same as
17 those under Alternative A. A total of 7,706 jobs and \$311.6 million in income would be
18 produced annually across all lake and river recreational activities under Alternative G over the
19 20-year LTEMP period.

20
21 Small reductions in use value and economic impact associated with lake-based
22 recreational activities under Alternative G compared to Alternative A would come primarily as a
23 result of changes in reservoir water levels, which would mean differences in exposure of beaches
24 and mudflats, and consequently a change in quality of recreational experience and reduced
25 visitor spending. Changes in use values associated with Glen Canyon angling and Upper and
26 Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips
27 would be primarily related to the equal monthly volumes that would occur year-round, and
28 consequently lower flows during the more popular summer months. Use values for Glen Canyon
29 day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-
30 water boating would not change, because demand for these activities would not be affected by
31 river levels under this alternative. With no changes in visitation for any of the river-based
32 activities, there would be no change in the economic impact of these activities under
33 Alternative G compared to Alternative A.

34
35 In addition to changes in generation and marketable capacity resulting from changes in
36 Glen Canyon Dam operations under Alternative G, there would also be forecasted increases in
37 the demand for electricity in the service territories of the eight largest Western customer utilities
38 and the planned retirement of existing powerplant generating capacity, meaning that an estimated
39 5,050 MW of new capacity would be built under Alternative G over the 20-year study period.
40 Using estimated capital and operating costs associated with providing additional capacity,
41 powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state
42 region, a difference of 3.9% compared to Alternative A, and \$875.3 million in earnings.
43 Operation of new powerplants with Alternative G would create 1,065 total jobs and
44 \$72.5 million in annual earnings associated with new jobs.
45

1 Although costs associated with replacing generation capacity no longer provided at Glen
2 Canyon Dam would mean changes in retail rates charged by Western customer utilities, and
3 consequently changes in the electric bills of residential customers, the cost of additional capacity
4 required to replace capacity lost at Glen Canyon Dam under Alternative G would have impacts
5 on electric bills paid by residential customers of the eight largest Western customer utilities, and
6 would mean the loss of 25 total (direct and indirect) jobs and \$1.2 million in earnings in the
7 seven-state region.

8
9 With no change in river visitation there would be no impacts on Tribal river boat rental
10 operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative G, and the
11 impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or
12 damage to culturally important plants and resources would be negligible, but impacts on Tribal
13 values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on
14 Tribes related to electricity sales would be higher (as much as \$1.34/MWh) from those on non-
15 Tribal customers, and would be greater (as much as \$2.84/MWh) than those under Alternative A.

16
17 In summary, under Alternative G there would be a decline in use values associated with
18 Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial
19 whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to
20 Alternative A. There would also be a decline in economic activity associated with Lake Powell
21 recreation. There would be no change in use values associated with Glen Canyon day-use rafting,
22 Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater
23 boating. There would also be no change in economic activity associated with river recreation.
24 There would be an increase in use values for Lower Grand Canyon private whitewater boating
25 and in use values and economic activity associated with Lake Mead recreation. There would also
26 be increased economic activity from customer utility capacity expansion, compared to
27 Alternative A, and reduced economic activity as a result of higher residential electric bills.

30 4.15 AIR QUALITY

31
32 This section describes potential impacts
33 of the LTEMP alternatives on ambient air quality
34 in the immediate vicinity of GCNP and over the
35 11-state study area within the Western
36 Interconnect, where the air quality would
37 potentially be affected by the proposed action.
38 The regional air quality setting is described in
39 Section 3.15.

Issue: How do alternatives affect emissions from other facilities and air quality in the Grand Canyon area and in the 11-state study area?

Impact Indicators:

- Visibility effects from sulfates and nitrates
- SO₂ and NO_x emissions

42 4.15.1 Analysis Methods

43
44 Glen Canyon Dam hydropower generation does not generate air emissions. However,
45 dam operations can affect emissions within the SLCA/IP system, which is referred to here as
46 “the system.” It also impacts emissions and ambient air quality over the 11-state Western

1 Interconnect region, which includes Arizona, California, Colorado, Idaho, Montana, Nevada,
2 New Mexico, Oregon, Utah, Washington, and Wyoming, because hydropower generation offsets
3 generation from other generating facilities (i.e., coal-fired, natural gas-fired,) in the Western
4 Interconnect. Differences among alternatives in the amount of generation at peak demand hours
5 could affect regional air emissions, if lost generation was offset by generation from coal, natural
6 gas, or oil units. The above discussion would also apply to Hoover Dam; the alternatives could
7 affect the seasonal pattern of Lake Mead elevations and, thus, power generation at Hoover Dam.
8 However, such effects at Hoover Dam are anticipated to be relatively small (Section 4.13).

9
10 Air quality issues within the study area are discussed in Section 3.15 and notably include
11 visibility degradation in Federal Class I areas. Coal, natural gas, and oil units emit SO₂ and NO_x,
12 which are precursors to sulfate and nitrate aerosols, respectively. These aerosols play an
13 important role in visibility degradation by contributing to haze. Among anthropogenic sources,
14 sulfate is a primary contributor to regional haze in the Grand Canyon, and nitrate is a minor
15 contributor. Effects on visibility are analyzed through a comparison of regional SO₂ and NO_x
16 emissions under the various alternatives.

17
18 To compute total air emissions under the alternatives, emissions were summed from all
19 generating facilities in the SLCA/IP system. This analysis was based on the analysis performed
20 for hydropower, which estimated electrical power contributions for the same facilities (results
21 are discussed in Section 4.13). Emissions were computed according to the estimated electricity
22 generation of each facility and for electricity traded on the spot market under each alternative by
23 calendar year. The spot market represents the interface of the system with the greater Western
24 Interconnect region and accounts for effects of Glen Canyon Dam operations outside of the
25 system. For individual powerplants in the system, pollutant emission factors (in pounds per
26 megawatt-hour [lb/MWh]) available in the *Emissions & Generation Resource Integrated*
27 *Database* (eGRID) (EPA 2014a) were used to compute emissions. For unspecified powerplants
28 (e.g., long term contract), composite emission factors were employed that are representative of
29 power generation from all types of powerplants currently in operation over the Western
30 Interconnect. Composite emission factors are estimated to be 0.74 and 1.07 lb/MWh for SO₂ and
31 NO_x, respectively. For spot market purchases and sales, composite emission factors were used
32 that are representative of power generation from gas powerplants currently in operation over the
33 Western Interconnect, based on the assumption that spot market generation is primarily to serve
34 peak loads. Composite emission factors are estimated to be 0.0083 and 0.266 lb/MWh for SO₂
35 and NO_x, respectively. For advanced natural-gas-fired simple cycle and combined cycle
36 generating units to be built in the future, emission factors in EIA (2013) were used:
37 0.001 lb/MMBtu for SO₂ for both simple cycle (0.0098 lb/MWh) and combined cycle
38 (0.0064 lb/MWh); 0.03 lb/MMBtu (0.29 lb/MWh) for simple cycle and 0.0075 lb/MMBtu
39 (0.048 lb/MWh) for combined cycle for NO_x. Note the difference in the expression of emission
40 factors employed from different sources. Emission factors for existing plants and the spot market
41 are based on emissions per electricity output, while those for future plants are based on emissions
42 per heat energy input (fuel burned). To make comparable estimates, the thermal efficiency of the
43 plant must be taken into account for the latter case.
44

1 Potential impacts on regional ambient air quality associated with dam operations are
2 compared in terms of air emissions among alternatives relative to air emissions for Alternative A
3 (No Action Alternative).
4
5

6 **4.15.2 Summary of Impacts** 7

8 The geographic area of potential impacts consists of the GCNP vicinity and the 11-state
9 Western Interconnect region. Table 4.15-1 presents potential impacts on ambient air quality that
10 would likely result from each alternative. Due to very small differences in SO₂ and NO_x
11 precursor emissions, negligible differences are expected among the alternatives with regard to
12 visibility and haze in the region.
13

14 Differences in emissions, and thus in impacts on air quality, under the LTEMP
15 alternatives depend on four factors that may act to increase or decrease total emissions under a
16 given alternative. These factors include:
17

- 18 • Total electricity generation at Glen Canyon Dam;
- 19
- 20 • Generation profile as characterized by the hourly, daily, and monthly release
21 pattern;
- 22
- 23 • Amount and timing of needed replacement capacity needed to offset reduced
24 Glen Canyon Dam capacity; and
- 25
- 26 • Amount of exports and imports of electricity to and from the spot market.
27

28 As total generation decreases, overall emissions increase because compensating
29 generation includes a component of combustion sources within the system. The differences
30 among the alternatives in total generation are relatively small (<2%), and are related to
31 differences in the amount of water that bypasses the turbines during HFEs.
32

33 The generation profile of alternatives reflects the degree to which generation can meet
34 peak demand. During low load periods Glen Canyon Dam electricity production displaces
35 generation from baseload units such as coal-fired units that tend to have high emission rates in
36 pounds (lb) of emissions per MWh generated; on-peak Glen Canyon generation displaces
37 peaking unit production, typically natural gas-fired combustion turbines, which have lower
38 emission rates than coal plants. Alternatives that have greater Glen Canyon Dam peaking
39 generation have reduced Glen Canyon Dam baseload generation and vice versa, given
40 approximately equal total flow volumes among the alternatives. Thus, fluctuating flow
41 alternatives with greater Glen Canyon Dam peaking power and lower baseload power tend to
42 result in higher SO₂ and NO_x emissions system-wide due the greater use of coal-fired facilities
43 within the system to compensate for reduced baseload generation at Glen Canyon Dam. Coal-
44 fired facilities have approximately an order of magnitude higher SO₂ and significantly higher

1 **TABLE 4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air**
 2 **Quality**

Air Quality	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions	Negligible increase in SO ₂ and NO _x emissions compared to Alternative A	Negligible decrease in SO ₂ emissions and no change in NO _x emissions compared to Alternative A	No change in SO ₂ emissions and negligible increase in NO _x emissions compared to Alternative A	Negligible increase in SO ₂ and NO _x emissions compared to Alternative A	Negligible decrease in SO ₂ and NO _x emissions compared to Alternative A	Negligible decrease in SO ₂ and negligible increase in NO _x emissions compared to Alternative A
Visibility ^a	No change from current conditions	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A
Air Quality in 11-State Western Interconnect Region							
SO ₂ emissions (tons/yr) ^b	42,465	42,471	42,463	42,465	42,466	42,448	42,453
	No change from current conditions	Negligible increase (0.01%)	Negligible reduction (-0.01%)	No change from current conditions	Negligible increase (<0.005%)	Negligible reduction (-0.04%)	Negligible reduction (-0.03%)
NO _x emissions (tons/yr) ^b	78,496	78,501	78,496	78,503	78,500	78,487	78,498
	No change from current conditions	Negligible increase (0.01%)	No change from current conditions	Negligible increase (0.01%)	Negligible increase (<0.005%)	Negligible reduction (-0.01%)	Negligible increase (<0.005%)

^a Visibility effects are estimated from expected changes in the emissions of sulfate and nitrate precursors, SO₂ and NO_x.

^b Total air emissions and percent change in emissions (compared to Alternative A) from combustion-related powerplants in the system averaged over the 20-year LTEMP period.

Source: EPA (2014b).

NO_x emissions than gas-fired facilities for a given amount of generation. Coal plants also produce more CO₂, a greenhouse gas, than do gas-fired plants. Effects of greenhouse gas emissions are discussed in Section 4.16.

The amount and timing of needed replacement capacity can also have an effect on total emissions. Steady flow alternatives, which do not include load following have reduced effective capacity, or maximum generating level, which must be compensated for by the construction and operation of new generation facilities in the system to meet current and future demands during peak load periods. New capacity is required sooner under steady flow alternatives (Section K.1.10.2 in Appendix K). New units would tend to be cleaner, more efficient, and less expensive to operate and therefore would tend to displace generation from higher emitting old units that serve the same type of duty (i.e., peaking unit) and would thus tend to reduce system

1 emissions slightly relative to fluctuating flow alternatives. Construction of new capacity and
2 retirement of existing plants are included in the hydropower analysis (Section 4.13) and in this
3 air quality analysis.
4

5 The relative amounts of exports and imports to and from the spot market also can affect
6 total emissions. Alternatives with greater net exports (sales) from the SLCA/IP system to the
7 spot market tend to have greater total emissions since fossil-fired powerplants in the SLCA/IP
8 system tend to have higher emission rates than Western Interconnect powerplants in states which
9 purchase the electricity, mostly in California. When the system buys external energy to serve
10 electricity demand, it needs to produce less power from its own internal resources thereby
11 reducing pollutants emitted by the system. Conversely, when the system sells power to the
12 Western Interconnect, it increases power production to support the spot energy transaction.
13 Emissions associated with spot market sales are accounted for because unit-level generation for
14 all facilities in the system (including the amount required for a sale) is multiplied by plant-level
15 emission factors. On the other hand, this exported energy via a spot market transaction will
16 reduce both generation and emissions in the overall 11-state Western Interconnect.
17

18 These factors have relatively small effects on emissions, and operate in sometimes
19 opposing directions with regard to total system emissions of SO₂, NO_x and CO₂. Thus, although
20 total emissions under the various alternatives are relatively similar, the relative differences result
21 from a complex combination of these four factors that can only be understood through detailed
22 modeling of emissions from individual generating facilities within the system under each of the
23 alternatives. The following paragraphs present the results of such modeling.
24

25 Electricity generation averaged over the LTEMP period at Glen Canyon Dam for each
26 alternative is shown in Figure 4.15-1. Little difference exists among alternatives, which range
27 from 4,178 to 4,255 GWh per year. Other powerplants in the system can be fossil fuel-fired,
28 renewable, hydro, or nuclear, and they depend on Glen Canyon Dam to provide uninterrupted
29 power to their customers; power generation is thus similarly unchanged among alternatives.
30 Under Alternative A, total SO₂ and NO_x emissions in the system averaged over the 20-year
31 LTEMP period are estimated to be about 42,465 tons/yr and 78,496 tons/yr, which amount to
32 about 10% and 3.0%, respectively, of total SO₂ and NO_x emissions over the Western
33 Interconnect region (see Table 3.16-3). Thus, air emissions from power generators in the system
34 are moderate contributors to total emissions in the Western Interconnect region. As shown in
35 Table 4.15-1, air emissions under other LTEMP alternatives are similar to those under
36 Alternative A. Differences from Alternative A range from -0.04 to 0.01% for SO₂ and from -
37 0.01 to 0.01% for NO_x. Differences in average annual emissions range from -18 to 5 tons/yr for
38 SO₂ and -10 to 6 tons/yr for NO_x, compared to those for Alternative A. Therefore, potential
39 impacts of dam operations under various alternatives on regional air quality would be very small.
40

41 Table 4.15-2 presents a breakdown of emission sources by generation technology type for
42 the generation facilities within the system and includes emissions for energy traded on the spot
43 market using a composite emission factor for facilities in the Western Interconnect region. The
44 table also shows power generation from Glen Canyon Dam under the various alternatives
45 relative to Alternative A, which produces the most energy. Alternatives F and G produce

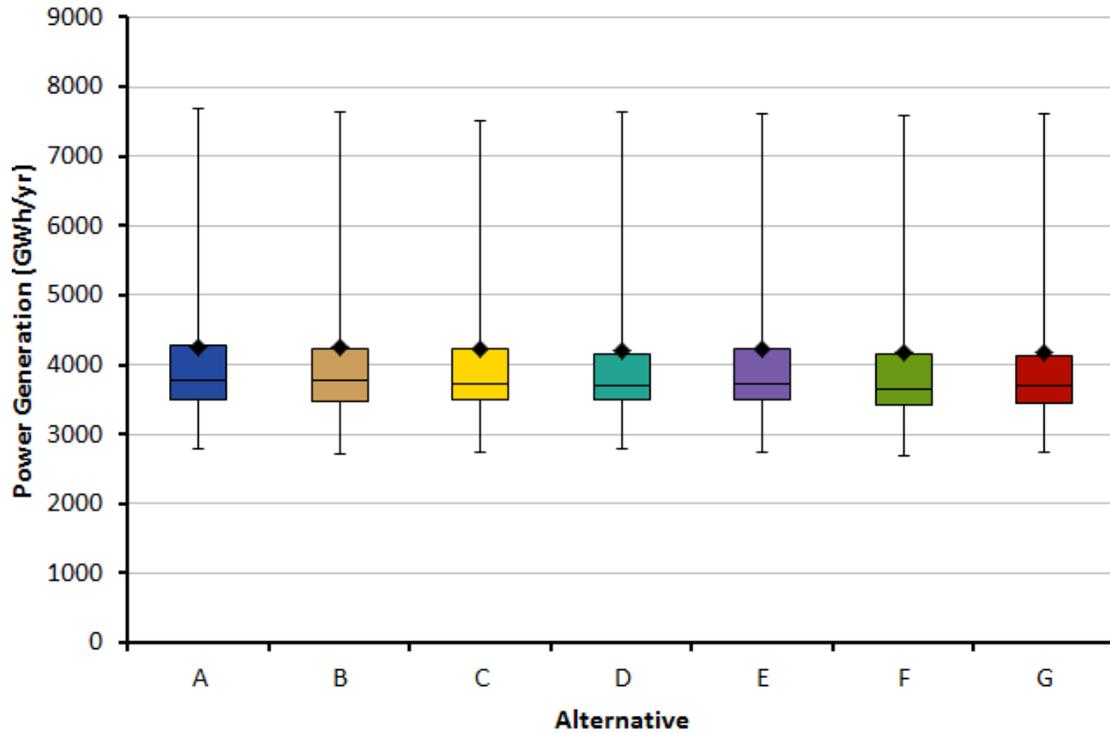


FIGURE 4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

relatively less hydropower energy than Alternative A (98.3% and 98.2%, respectively) because they have more HFEs in which a portion of released water bypasses the powerplant turbines.

SO₂ and NO_x emissions within the system are dominated by steam turbine technologies, mainly coal-fired powerplants (Table 4.15-2). Considering generation by facilities within the system (approximately 35 primary facilities), the differences among alternatives in estimated emissions are miniscule, ranging over only 0.05% for SO₂ and 0.02% for NO_x (system subtotal). Estimated differences among alternatives reflect slight differences in the contributions from various powerplant technologies; these are attributed to small differences in baseload and peaking energy provided by Glen Canyon Dam. Gas turbine peaking plant technologies produce lower SO₂ and lower NO_x emissions than baseload coal-fired plants. Thus, offsetting gas turbine peaking power with hydropower from Glen Canyon Dam has a potentially lower effect on total system emissions than does offsetting coal-fired baseload with baseload energy from Glen Canyon Dam.

This effect may be seen by comparing emissions subtotals by technology type under fluctuating flow and steady flow alternatives. For both SO₂ and NO_x, steam turbine (coal plant) emissions are slightly lower under Alternatives F and G, reflecting possible reductions in baseload emissions from coal plants offset by increased baseload energy from Glen Canyon Dam, even though these two alternatives generate <2% less Glen Canyon Dam energy than the

1 **TABLE 4.15-2 Distributions of SO₂ and NO_x Emissions Averaged over the 20-Year LTEMP**
2 **Period by Alternative**

Generation Type	Alternative						
	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Total Glen Canyon Dam Power Generation Relative to Alternative A (MW-hr/day) (% of Alternative A)	11,650 (100%)	11,616 (99.7%)	11,566 (99.3%)	11,525 (98.9%)	11,571 (99.3%)	11,449 (98.3%)	11,438 (98.2%)
SO ₂ Emissions (tons per year)							
System Power Generation							
Combined Cycle	44	44	44	44	44	44	44
Composite ^a	606	607	606	607	607	608	606
Gas Turbine	13	13	13	13	13	15	14
Internal Combustion	1	1	1	1	1	1	1
Steam Turbine	41,805	41,810	41,802	41,804	41,805	41,785	41,792
System Subtotal	42,469	42,474	42,467	42,469	42,470	42,452	42,457
Spot Market ^b							
Sales (emissions subtracted)	-16	-15	-16	-16	-16	-16	-16
Purchases (emissions added)	12	12	12	12	12	12	12
Spot Market Subtotal	-4	-4	-4	-4	-4	-4	-4
Total (System + Spot Market)	42,465	42,471	42,463	42,465	42,466	42,448	42,453
NO _x Emissions (tons per year)							
System Power Generation							
Combined Cycle	655	654	656	657	656	658	658
Composite ^a	869	870	869	870	870	871	869
Gas Turbine	271	265	282	278	277	307	300
Internal Combustion	24	24	24	24	24	24	24
Steam Turbine	76,800	76,806	76,796	76,799	76,801	76,766	76,781
System Subtotal	78,620	78,620	78,626	78,629	78,628	78,626	78,632
Spot Market Sales ^b							
Sales (emissions subtracted)	-499	-492	-509	-503	-506	-520	-514
Purchases (emissions added)	375	374	378	377	378	381	380
Spot Market Subtotal	-124	-118	-130	-126	-128	-139	-134
Total (System + Spot Market)	78,496	78,501	78,496	78,503	78,500	78,487	78,498

^a Unspecified generation type.

^b “Sales” refers to sales of power by system utilities to non-system utilities within the Western Interconnect. Sales result in a net credit to total Western Interconnect emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. “Purchases” refers to purchases by system utilities from non-system utilities within the Western Interconnect. Emissions related to these purchases are added to the total emissions in the Western Interconnect.

1 fluctuating flow alternatives. Likewise, SO₂ emissions for gas technologies are slightly higher
2 for Alternatives F and G, reflecting increased peaking generation from gas plants compensating
3 for lack of peaking ability under these two alternatives.
4

5 The effects of the spot market on total system emissions are shown in Table 4.15-2. The
6 spot market contribution to emissions is small (about <0.2% of total emissions from the system);
7 however, for NO_x the spot market contributes about 60% more than the in-system component to
8 differences among alternatives (21 tons/yr and 13 tons/yr, respectively). The spot market has no
9 effect on differences in SO₂ emissions, since spot market emissions are very small and similar
10 (4 tons/yr) (Table 4.15-1). The spot market component is shown as a negative value in the table,
11 reflecting a net export of power from the system. When power is exported (i.e., sold) to a utility
12 outside of the system, it is assumed that the purchaser will generate less energy from its own
13 power resources, resulting in lower total emissions in the Western Interconnect region.
14 Therefore, we apply an emissions credit for energy that is bought by utilities outside of the
15 system. Because we do not model external utilities in detail, we cannot pinpoint the exact source
16 of this emission reduction. Therefore, we use composite emission factors representative of power
17 generation in the 11-state Western Interconnect region. Note, however, that since we model all
18 generating resources within the system we are accounting for the increased generation and hence
19 emissions associated with the exported energy.
20

21 Net NO_x emissions related to spot market sales and purchases are lowest (greatest
22 negative value) for the steady flow Alternatives F and G, and highest for the fluctuating flow
23 Alternatives B and A. Net SO₂ spot market emissions are essentially the same across
24 alternatives. This result can be explained by considering in-system generation selling to the spot
25 market. Under steady flow Alternatives F and G, the Glen Canyon Dam powerplant does not
26 provide peaking power, while under fluctuating flow Alternatives A-E it does. Since spot market
27 sales typically serve peak demand, NO_x emissions from sales to the spot market are therefore
28 higher for Alternatives F and G, since other, typically gas-fired, facilities in the system provide
29 peak generation. Such facilities generate NO_x emissions, but very little SO₂, so there is no effect
30 on the latter emission.
31

32 Given the very small differences in the estimated emissions after considering all of the
33 factors discussed above and in light of the uncertainty of emissions modeling, it may be
34 concluded that emissions would be similar under all of the alternatives.
35
36

37 **4.15.3 Alternative-Specific Impacts** 38

39 Although differences are expected in potential ambient air quality and associated impacts
40 among the various alternatives, potential air quality impacts are anticipated to be negligible. The
41 modeled differences among alternatives are presented below. Detailed information on
42 alternatives and hydropower assumptions and modeling can be found in Sections 2.3 and 4.13,
43 respectively.
44

1 **4.15.3.1 Alternative A (No Action Alternative)**
2

3 Under Alternative A (No Action Alternative), annual power generation at Glen Canyon
4 Dam would range from 2,781 to 7,677 GWh, with an average of 4,225 GWh, over the 20-year
5 LTEMP period. Coal-fired steam plants account for the vast majority of these emissions; that is
6 about 98% of both SO₂ and NO_x emissions. In addition, total LTEMP-related annual air
7 emissions from power generation, system emissions plus changes in the Western Interconnect
8 would range from 41,392 to 42,991 tons/yr with an average of 42,465 tons/yr for SO₂, and from
9 77,121 to 80,005 tons/yr with an average of 78,496 tons/yr for NO_x. These annual-average
10 emissions for SO₂ would be about 10% and for NO_x would be about 3.0% of the total air
11 emissions over the Western Interconnect region (see Table 3.16-3).
12
13

14 **4.15.3.2 Alternative B**
15

16 Under Alternative B, total LTEMP-related annual-average air emissions are
17 42,471 tons/yr for SO₂ and 78,501 tons/yr for NO_x; these values are about 0.01% higher than
18 those under Alternative A. Annual-average power generation at Glen Canyon Dam under this
19 alternative is estimated to be about 99.7% of that under Alternative A. Total annual emissions
20 from power generation in the region are slightly higher than those under Alternative A, due to
21 the combined effects of the four factors described in Section 4.15.2. Consequently, there would
22 be negligible differences in impacts on regional ambient air quality between Alternative B and
23 Alternative A.
24
25

26 **4.15.3.3 Alternative C**
27

28 Under Alternative C, total LTEMP-related annual-average air emissions are
29 42,463 tons/yr for SO₂ and 78,496 tons/yr for NO_x; these values are about 0.01% lower than and
30 the same as those under Alternative A, respectively. Annual-average power generation at Glen
31 Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A.
32 Total annual emissions from power generation in the region are slightly lower than or the same
33 as those under Alternative A, due to the combined effects of the four factors described in
34 Section 4.15.2. Consequently, there would be negligible differences in impacts on regional
35 ambient air quality between Alternative C and Alternative A.
36
37

38 **4.15.3.4 Alternative D (Preferred Alternative)**
39

40 Under Alternative D, total LTEMP-related annual-average air emissions are
41 42,465 tons/yr for SO₂ and 78,503 tons/yr for NO_x; these values are the same as and about
42 0.01% higher than those under Alternative A, respectively. Annual-average power generation at
43 Glen Canyon Dam under this alternative is estimated to be about 98.9% of that under
44 Alternative A. Total annual emissions from power generation in the region are the same as or
45 slightly higher than those under Alternative A, due to the combined effects of the four factors

1 described in Section 4.15.2. Consequently, there would be negligible differences in impacts on
2 regional ambient air quality between Alternative D and Alternative A.
3
4

5 **4.15.3.5 Alternative E**

6
7 Under Alternative E, total LTEMP-related annual-average air emissions are
8 42,466 tons/yr for SO₂ and 78,500 tons/yr for NO_x; these values are about <0.005% higher than
9 those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam
10 under this alternative is estimated to be about 99.3% of that under Alternative A. Total annual
11 emissions from power generation in the region are slightly higher than those under
12 Alternative A, due to the combined effects of the four factors described in Section 4.15.2.
13 Consequently, there would be negligible differences in impacts on regional ambient air quality
14 between Alternative E and Alternative A.
15
16

17 **4.15.3.6 Alternative F**

18
19 Under Alternative F, total LTEMP-related annual-average air emissions are
20 42,448 tons/yr for SO₂ and 78,487 tons/yr for NO_x; these values are about 0.04 and 0.01%,
21 respectively, lower than those under Alternative A. Annual-average power generation at Glen
22 Canyon Dam under this alternative is estimated to be about 98.3% of that under Alternative A.
23 Total annual emissions from power generation in the region are slightly lower than those under
24 Alternative A, due to the combined effects of the four factors described in Section 4.15.2.
25 Consequently, there would be negligible differences in impacts on regional ambient air quality
26 between Alternative F and Alternative A.
27
28

29 **4.15.3.7 Alternative G**

30
31 Under Alternative G, total LTEMP-related annual-average air emissions are
32 42,453 tons/yr for SO₂ and 78,498 tons/yr for NO_x; these values are about 0.03 and <0.005%,
33 respectively, lower and higher than those under Alternative A. Annual-average power generation
34 at Glen Canyon Dam under this alternative is estimated to be about 98.2% of that under
35 Alternative A. Total annual emissions from power generation in the region are slightly lower or
36 higher than those under Alternative A, due to the combined effects of the four factors described
37 in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional
38 ambient air quality between Alternative G and Alternative A.
39
40

1 **4.16 CLIMATE CHANGE**
2

3 There is the potential for the LTEMP to
4 affect climate change indirectly through changes
5 in dam operations, and for dam operations under
6 the LTEMP to be affected by climate change.
7 Although each of the LTEMP alternatives would
8 generate approximately the same amount of
9 electrical power,¹⁴ there are relatively large
10 differences in the monthly and within-day pattern
11 of releases that affect hydropower capacity.
12 These differences in available capacity affect
13 how other power facilities in the region respond
14 to changes in demand, and in this way can affect the total system emission of carbon dioxide
15 (CO₂) and other greenhouse gases (GHGs) (Section 4.15 describes the effect of Glen Canyon
16 Dam operations on the power system and the emissions of criteria pollutants). In addition to
17 these potential effects on climate change, operations over the 20-year LTEMP period could be
18 affected by climate-driven changes in hydrology (inflow patterns and evaporation rates) and
19 sediment inputs. Reductions in inflow due to changes in precipitation and increases in
20 evaporation rates resulting from increases in temperature could result in decreases in the
21 elevation of Lake Powell, with subsequent reductions in power generation resulting from
22 decreased head, and potentially an increase in the frequency of dropping below the power pool.
23

Issue: How could the LTEMP affect or be affected by climate change?

Impact Indicators:

- Changes in CO₂ and other GHG emissions under different LTEMP alternatives
- Climate-driven changes in hydrology and sediment inputs over the 20-year LTEMP period

24
25 **4.16.1 Analysis Methods**
26

27
28 **4.16.1.1 Effects of LTEMP Alternatives on Climate Change**
29

30 The buildup of heat-trapping GHGs can over time warm Earth's climate and result in
31 adverse effects on ecosystems and human health and welfare. Thus, cumulative GHG emissions
32 can be used as a surrogate to assess climate-change impacts. Such effects would be global and
33 are not particularly sensitive to GHG source locations because GHGs are mostly long-lived and
34 spread across the entire globe.
35

36 Glen Canyon Dam operation does not generate GHG emissions, but dam operations can
37 indirectly affect climate change, regionally and globally, through varying contributions to the
38 total mix of power generation in the region, which also includes coal-fired, natural gas-fired,
39 hydroelectric, nuclear, and renewable generation sources. For the purposes of this analysis, the
40 principal GHG of concern is CO₂, which accounts for more than 99% of GHG emissions related
41 to power generation. However, facility- or technology-specific GHG emission factors also

¹⁴ The relatively small expected differences among alternatives in the amount of total annual generation relate to the alternative-specific frequency of HFEs. Approximately 14,000 cfs of a 45,000-cfs HFE would be released through the bypass tubes, which do not generate power. Alternatives differ substantially in the frequency of HFEs (Section 4.2).

1 consider other GHGs, such as methane (CH₄) and nitrous oxide (N₂O), albeit to a small degree.
2 The above discussion would also apply to Hoover Dam, since the alternatives could affect the
3 seasonal pattern of Lake Mead elevations, and, thus, power generation at Hoover Dam. However,
4 such effects at Hoover Dam are anticipated to be relatively small and have been found to
5 generally offset corresponding effects at Glen Canyon Dam (Section 4.13, thus reducing
6 differences among alternatives, but not changing the ranking of effects.
7

8 To compute total GHG emissions under the alternatives, emissions were summed from
9 all generating facilities primarily affected by Glen Canyon Dam operations, referred to as “the
10 system,” as was done for SO₂ and NO_x for the air quality analysis (Section 4.15). This analysis
11 was based on the analysis performed for hydropower, which estimated electrical power
12 contributions for the same facilities, the results of which are discussed in Section 4.13. GHG
13 emissions were computed according to the estimated annual electricity generation of each facility
14 and for electricity traded on the spot market under each alternative. For individual powerplants,
15 GHG emission factors (in lb/MWh) available in eGRID (EPA 2014a) were used to compute
16 GHG emissions. For unspecified powerplants (e.g., long-term contract), composite emission
17 factors representative of power generation from all types of powerplants that are currently in
18 operation over the 11-state Western Interconnect region (Arizona, California, Colorado, Idaho,
19 Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) were employed. A
20 composite emission factor for GHGs is estimated to be 963 lb/MWh (0.437 MT/MWh) for CO₂
21 equivalent (CO₂e).¹⁵ For spot market purchases and sales, a composite GHG emission factor for
22 gas powerplants operating in the Western Interconnect was used, and was estimated to be
23 888 lb/MWh (0.403 MT/MWh) CO₂e. For advanced natural gas-fired generating units projected
24 to be built in the future, an emission factor from the EIA (2013) of 117 lb/MMBtu
25 (0.053 MT/MMBtu) for CO₂ was used for both simple-cycle (1,141 lb/MWh [0.518 MT/MWh])
26 and combined cycle (752 lb/MWh [0.341 MT/MWh]) units.
27

28 Potential impacts on climate change associated with dam operations are evaluated for the
29 LTEMP alternatives though a comparison of GHG emissions to those for Alternative A
30 (no action alternative).
31
32

33 **4.16.1.2 Effects of Climate Change on Hydrology and Downstream Resources**

34
35 The effects of climate change on hydrology were treated as an uncertainty in the analyses
36 of hydrology and downstream resource impacts, rather than by means of a full-fledged climate
37 analysis and adaptation approach. The LTEMP DEIS has the more limited scope of evaluating
38 future dam operations, management actions, and experimental options to provide a framework
39 for adaptively managing Glen Canyon Dam over the next 20 years to protect and minimize
40 adverse impacts on downstream natural and cultural resources in GCNRA and GCNP.
41 Accordingly, DOI used a sensitivity analysis approach to see how robust the alternatives would
42 be with regard to their impact on resources under climate change.

¹⁵ CO₂e is a measure used to compare the emissions from various GHGs on the basis of their global warming potential, defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO₂ over a specific time period (usually 100 years).

1 The Basin Study (Reclamation 2012e) suggested there could be significant increases in
2 temperature and decreases in water supply to the Colorado River system below Glen Canyon
3 Dam over the next 50 years, driven by global climate change. The magnitude of these changes is
4 uncertain. In addition, there could be changes to sediment input (especially from the Paria and
5 Little Colorado Rivers), driven by complex local and regional climate changes, but the direction
6 and magnitude of these changes are uncertain. Water supply, sediment supply, and temperature
7 are important factors that affect all of the resources under consideration in the LTEMP DEIS.
8

9 The approach used in this DEIS treats climate change as an external uncertainty and
10 analyzes the robustness of the alternatives to uncertainties in the water and sediment inputs. This
11 approach required: (1) use of 21 hydrologic and 3 sediment scenarios based on historic
12 conditions; (2) estimation of the likelihood of the scenarios under climate change; and
13 (3) analysis of the impacts of alternatives under all hydrologic and sediment scenarios. The
14 approach analyzed how robust the alternatives would be to climate change-driven hydrologic and
15 sediment inputs. For the climate-change analysis, the 21 hydrologic traces used in the LTEMP
16 analysis were weighted according to their frequency of occurrence (based on mean annual inflow
17 to Lake Powell) in the Basin Study's 112 simulations. Figure 4.16-1 shows the weights assigned
18 to each hydrologic trace. As shown in Figure 4.16-2, the 21 hydrologic traces were not
19 representative of the full range of expected inflow variation under a climate-change scenario and
20 did not include the driest traces expected under climate change. About 30% of the forecast
21 distribution was not captured by the historic traces. Details of the approach are presented in
22 Appendix D.
23

24 Modeling results for downstream resource effects were generated for the 21 historic
25 hydrology traces and 3 historic sediment traces. For the analyses presented in Sections 4.2
26 through 4.10, the hydrology traces were weighted equally to represent their equal probability of
27 occurrence in the absence of climate change. The climate-change weights shown in
28 Figure 4.16-1 were applied to the modeled results for each trace to represent their probability of
29 occurrence under climate change.
30

31 32 **4.16.2 Summary of Impacts**

33 34 35 **4.16.2.1 Effects of LTEMP Alternatives on Climate Change**

36
37 Table 4.16-1 presents total estimated GHG emissions within the system for each
38 alternative. These emissions are an indication of the potential relative impact of the alternatives
39 on climate change.
40

41 For estimating GHG emissions attributable to Glen Canyon Dam operations, projected
42 power generation at the dam was averaged over the 20-year LTEMP period (Figure 4.15-1).
43 Little difference exists among the alternatives, which range from 4,178 to 4,255 GWh per year,
44 amounting to 1.8%. Power generation from other powerplants in the system and in the Western

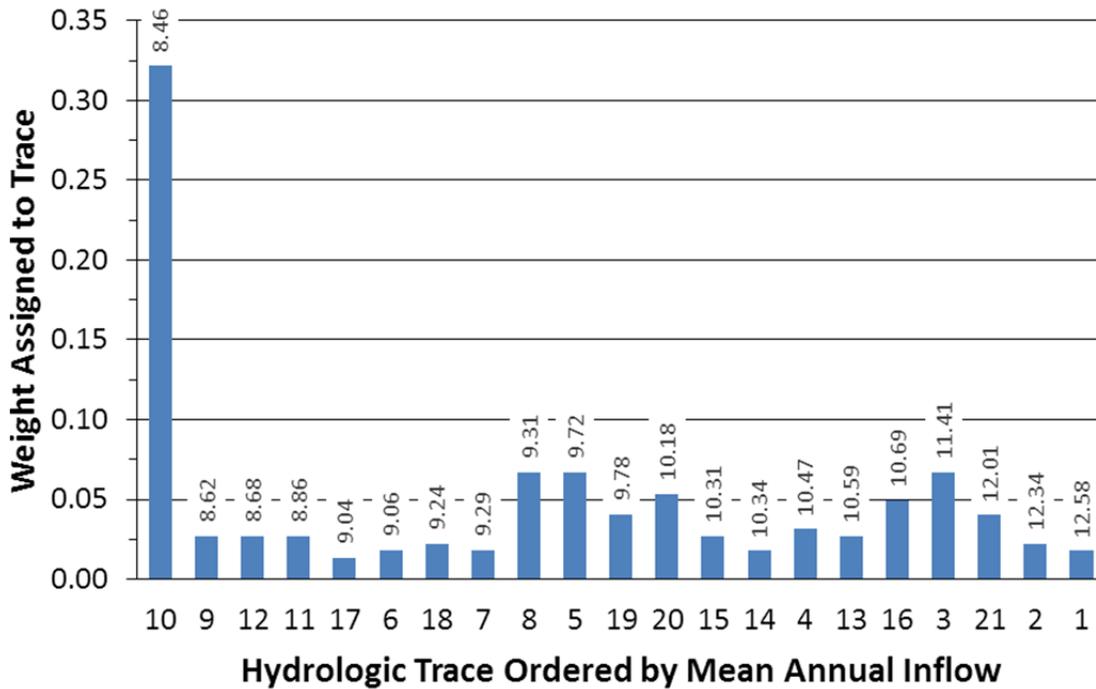
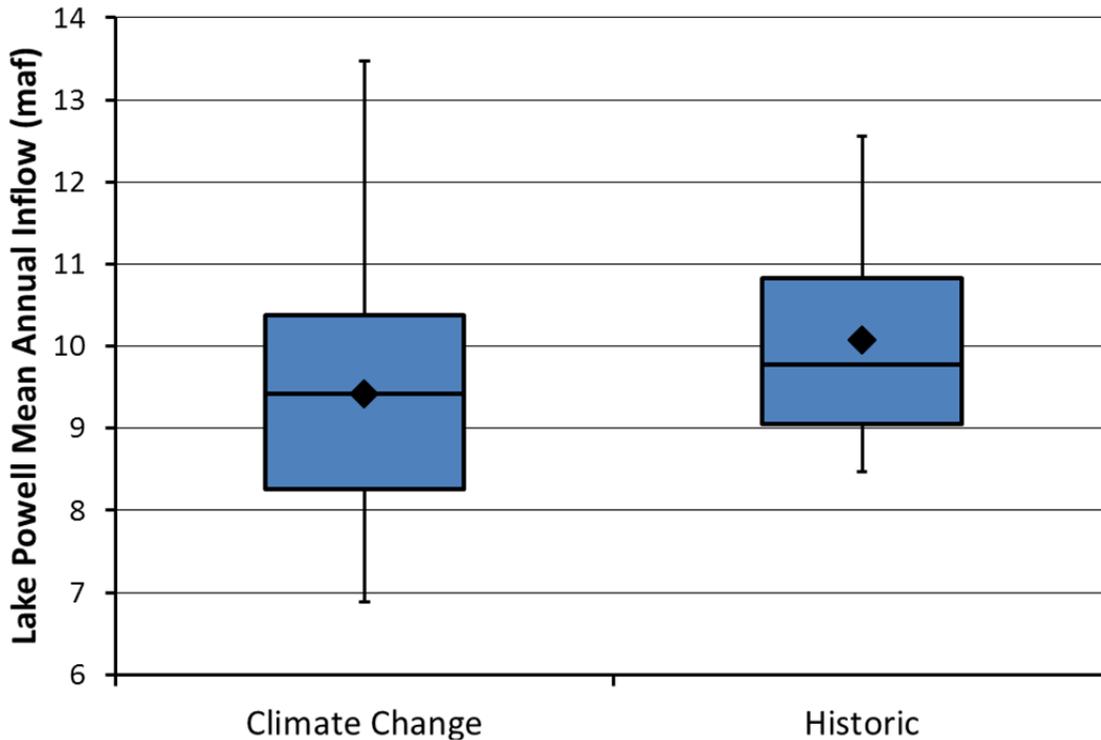


FIGURE 4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions under Climate Change (Numbers at top of bars are mean annual inflow of each trace in million acre-feet.)

Interconnect region also would be similar among alternatives. For Alternative A (no action alternative), total GHG emissions in the system averaged over the 20-year LTEMP period are estimated to be about 55,177,668 MT/yr, which amounts to about 4.5% and 0.81% of total GHG emissions over the Western Interconnect region and the United States, respectively (Table 3.15-3, Section 3.15.3). Thus, GHG emissions from power generation are relatively small contributors to total GHG emissions in the region.

GHG emissions under other LTEMP alternatives would have negligible differences from those under Alternative A, ranging from an increase of 5,900 MT/yr (Alternative B) to 44,522 MT/yr (Alternative F), considering total emissions (system generation plus spot market sales and purchases). On a percentage basis, differences from Alternative A would range from 0.011% to 0.081%. The system includes 35 power generation facilities analyzed individually. The spot market reflects the effects of Glen Canyon Dam operations on the larger Western Interconnect region and represents an offset of about 1% of system emissions (Table 4.16-1).

In light of the 1.8% range in Glen Canyon Dam hydropower generation under the alternatives, and assuming that reduction in power generation at Glen Canyon Dam is made up by other generation facilities in the system, the smaller range in GHG emissions of only 0.081% suggests that reduced hydropower energy from, for example, Alternatives F and G does not result in a corresponding increase in GHG emissions from compensating generation at other



1

2 **FIGURE 4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile,**
3 **25th Percentile, Minimum, and Maximum Values for 112 Climate-Change Inflow Traces**
4 **and 21 Historic Inflow Traces (Means were calculated as the average for all years within**
5 **each of the traces. Note that diamond = mean; horizontal line = median; lower extent of**
6 **box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum;**
7 **upper whisker = maximum.)**

8

9

10 thermal powerplants in the system. This result may be explained by examining the effects of
11 powerplant mix and capacity expansion on emissions under the various alternatives. With respect
12 to powerplant mix, the Glen Canyon Dam powerplant under the steady-flow Alternatives F and
13 G does not serve peak loads, but does so under the fluctuating-flow Alternatives A through E,
14 offsetting GHG emissions from other peaking facilities in the system, mainly gas turbines.
15 Conversely, steady-flow alternatives can provide a higher level of baseload power, which can
16 offset emissions from other baseload facilities in the system, mainly coal-fired facilities with
17 relatively high GHG emissions compared to gas turbines. More detailed discussion of these
18 factors is presented in Section 4.15.2.

19

20

21

22

23

24

25

26

Reviewing projected GHG emissions at specific powerplants within the system, the steady-flow Alternatives F and G are expected to produce lower GHG emissions from coal-fired plants (categorized as steam turbine technologies) and higher GHG emissions from gas turbine plants as compared to the fluctuating-flow Alternatives A through E. This comparison supports the conclusion that Alternatives F and G tend to offset a relatively greater amount of baseload power at combustion facilities in the system than do Alternatives A through E, while the latter alternatives offset relatively more emissions from gas turbines that provide peaking power.

1 **TABLE 4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions**

GHG Emissions Source	GHG Emissions by Alternative (MT/yr) ^{a,b}						
	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Overall summary of impacts	No change from current conditions.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.
System power generation							
Combined cycle	5,871,619	5,867,894	5,875,470	5,878,837	5,876,226	5,880,006	5,885,763
Composite ^c	711,604	712,068	711,574	712,296	712,186	713,199	711,081
Gas Turbine	622,805	611,925	661,049	646,520	647,637	730,920	695,498
Internal combustion	1,726	1,721	1,680	1,728	1,711	1,688	1,706
Steam turbine	48,344,640	48,348,638	48,341,590	48,343,248	48,344,880	48,319,488	48,332,026
System subtotal	55,552,395	55,542,246	55,591,363	55,582,629	55,582,640	55,645,301	55,626,074
Spot market ^d							
Sales (emissions subtracted)	-1,512,509	-1,493,787	-1,543,444	-1,525,109	-1,536,444	-1,577,799	-1,560,383
Purchases (emissions added)	1,137,782	1,135,108	1,147,910	1,143,056	1,147,975	1,154,687	1,152,937
Spot market subtotal	-374,727	-358,679	-395,534	-382,053	-388,469	-423,112	-407,447
Total emissions (system + spot market)^e	55,177,668	55,183,567	55,195,829	55,200,576	55,194,171	55,222,189	55,218,627
	No change from current conditions	0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase
Change in Total Emissions	0	5,899	18,161	22,908	16,503	44,521	40,959
		0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase
Difference from Alternative A (MT/yr)	0	5,900	18,161	22,908	16,503	44,522	40,960
Total emissions as % of total U.S. GHG emissions ^f	No change from current conditions	0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase

Footnotes on next page.

TABLE 4.16-1 (Cont.)

-
- a GHG emissions are expressed in CO₂e.
 - b GHG emissions (metric tons) from combustion-related powerplants in the system or in the region averaged over the 20-year LTEMP period. To convert from metric ton to ton, multiply by 1.1023.
 - c Unspecified generation type.
 - d “Sales” refers to sales of power by system utilities to non-system utilities within the Western Interconnect. Sales result in a net credit to total Western Interconnect emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. “Purchases” refers to purchases by system utilities from non-system utilities within the Western Interconnect. Emissions related to these purchases are added to the total emissions in the Western Interconnect.
 - e The 2014 CEQ Draft Guidance on GHG Emissions state in regard to GHG emissions that warrant quantitative disclosure: “In considering when to disclose projected quantitative GHG emissions, CEQ is providing a reference point of 25,000 metric tons of CO₂-e emissions on an annual basis below which a GHG emissions quantitative analysis is not warranted unless quantification below that reference point is easily accomplished. This is an appropriate reference point that would allow agencies to focus their attention on proposed projects with potentially large GHG emissions.”
 - f U.S. total GHG emissions at 6,810.3 million MT/yr CO₂e in 2010 (EPA 2013d).

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Similarly, with respect to the effects of future capacity expansion, new thermal powerplants constructed to replace reduced capacity under Alternatives F and G would utilize technologies that are more efficient than most existing thermal powerplants and would produce less GHG emissions. Excess energy produced by these new plants sold to the spot market could displace generation and emissions at less efficient combustion units in the Western Interconnect region, resulting in a net reduction of emissions overall relative to fluctuating-flow alternatives in which Glen Canyon Dam utilizes some of its capacity to serve peak load. The combined effects of new capacity and differences in the thermal powerplant mix under the various alternatives result in negligible differences in total GHG emissions among alternatives.

GHG emissions under the alternatives can also be compared to total U.S. GHG emissions at 6,810.3 million MT CO₂e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions relative to total U.S. GHG emissions are less than 1% and range from 0.8102 (Alternative A) to 0.8109% (Alternative F). Therefore, potential impacts of dam operations under various alternatives on climate change are expected to be negligible.

CO₂, CH₄, and N₂O are emitted from the reservoirs associated with the Glen Canyon Dam, Lake Powell, and Lake Mead. For example, CH₄ from large dams accounted for about 4% of human-caused climate change (Lima et al. 2008). GHG emissions from biomass decay, including CH₄, in such reservoirs, have been a subject of recent debate (Pacca and Horvath 2002). Through consumption of atmospheric CO₂ by photosynthesis in plankton and aquatic plants in reservoirs, net CO₂ emissions from dam operations may be small, and uptake by reservoirs can occasionally exceed emissions. Emissions of CH₄ are possible from turbines and spillways and downstream of dams.

4.16.2.2 Effects of Climate Change on Hydrology and Downstream Resources

As discussed in Section 4.16.1.2, the climate-change analysis approach used the historic hydrology as its basis, but gave greater weight to drier years to represent their expected increased frequency of occurrence under a climate-change scenario. As shown in Figure 4.16-2, this approach underestimated the occurrence of the driest years, but it allows a determination of the robustness of the alternatives to climate-change uncertainty.

Figure 4.16-3 presents the differences between historic and climate-change-weighted values of mean daily flow and mean daily change in flow for the LTEMP alternatives as a percentage of the historic values for the 25th percentile and mean of the two variables. Negative values indicate a decrease in the value under the climate-change scenario, while positive values indicate an increase under the climate-change scenario. Of the values examined (minimum, maximum, 25th percentile, 50th percentile, 75th percentile, and mean), the 25th percentile (representing flow under drier conditions) was the most affected. There was no difference between historic and climate-change-weighted minimum and maximum values, but this is an artifact of the weighting approach used. Because mean monthly volume equals the mean daily flow times the number of days in each month, the percentage differences in that variable are identical to those shown for mean daily flow in Figure 4.16-3. The following conclusions can be drawn from the patterns observed in Figure 4.16-3:

- The 25th percentile values of mean daily flow (and mean monthly volume values) would be very similar from October through March under climate-change and historic scenarios for all alternatives. The differences for all alternatives between historic and climate-change scenarios would increase month-by-month through August. The trend is toward lower mean daily flows under climate change, which reaches a maximum difference of about 10% to 18% (decrease from historic values) in August. In general, the differences among alternatives with respect to the effects of climate change on mean daily flow would be similar.
- Mean values of mean daily flow (and values of mean monthly volume) would follow a pattern similar to that of the 25th percentile values of mean daily flow, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternative F in July and August, when flow would be even lower with climate change than under other alternatives.

The 25th percentile values of mean daily change under the climate-change scenario would be very similar to historic values from October through June for all alternatives, but would be higher than historic for July, August, and September for all alternatives except for the steady-flow Alternatives F and G. Under the drier conditions of climate change and lower mean daily flows, there is more flexibility to provide a wider range of flows within a day and still meet other operational constraints. It should be noted that the differences in mean daily change would be less than 1,000 cfs.

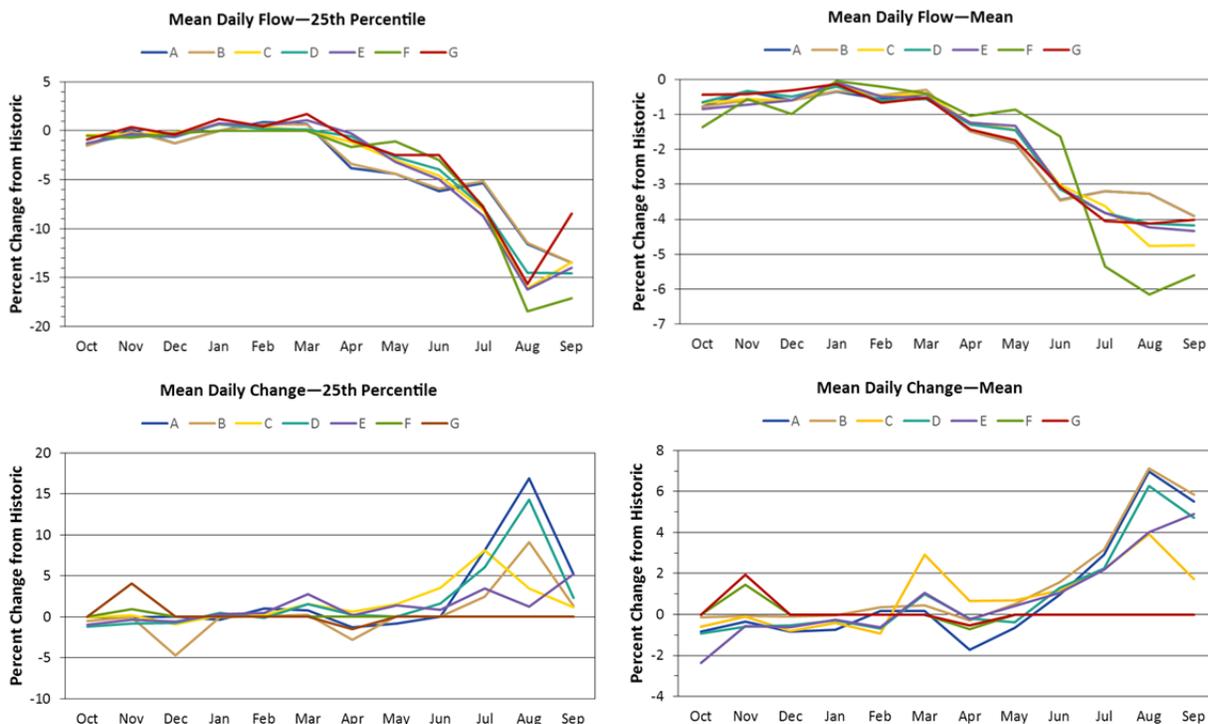


FIGURE 4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean Daily Flow and Mean Daily Change in Flow by Month for LTEMP Alternatives

- Mean values of mean daily change would follow a pattern similar to that of the 25th percentile values of mean daily change, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternatives A, B, and D in August, when daily change would be even higher with climate change than under other alternatives.

The monthly increase in climate-change effects in mean daily flow and mean monthly volume results from operation of the dam based on the inflow forecast for the water year. Typically, operations in October, November, and December use volumes for an 8.23-maf year, with adjustments made in later months as forecasts indicate a drier or wetter year (Figure 4.2-1). Early forecasts (e.g., January) are subject to considerable uncertainty, and it is usually not until the April forecast that a reasonable identification of the annual volume can be made. Using this operational strategy under climate change would result in less water needing to be released after April, and therefore an increasing deviation from the historic pattern.

These differences in hydrology would influence the relative effect of LTEMP alternatives on resources, but, in general, the analysis conducted for this DEIS indicates the differences would be relatively small and not differ greatly among alternatives. Table 4.16-2 provides an overview of the expected effects on downstream resources. Under climate change, the impacts of most or all LTEMP alternatives would be less on sediment resources, humpback chub, trout,

1 riparian vegetation, Grand Canyon cultural resources, Tribal values, and most recreation metrics,
2 but there would be a reduction in the value of hydropower generation and capacity and an
3 increase in impacts on Glen Canyon cultural resources.
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6 **4.16.3 Alternative-Specific Impacts**

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8 Although there are expected to be minor differences in the emissions of GHGs among the
9 various alternatives, potential impacts on climate change are anticipated to be negligible. Minor
10 differences among alternatives are presented below. Detailed information on alternatives and
11 hydropower assumptions and modeling can be found in Sections 2.3 and 4.13, respectively. The
12 effects of climate change on hydrology and downstream resources are also presented.
13
14

15 **4.16.3.1 Alternative A (No Action Alternative)**

16

17 Under Alternative A (no action alternative), annual power generation would range from
18 2,781 to 7,677 GWh, with an average of 4,255 GWh over the 20-year (2014–2033) period. Total
19 annual GHG emissions in the system related to power generation at the Glen Canyon Dam would
20 range from 52,014,751 to 59,909,459 MT (from 57,336,449 to 66,038,875 tons), with an average
21 of 55,177,668 MT (60,822,967 tons). These annual average GHG emissions would be about
22 4.5% and 0.81%, respectively, of the total GHG emissions over the Western Interconnect region
23 and in the United States (see Table 3.15-3 and Section 3.15.3).
24

25 Based on the modeling performed and climate change weights applied to account for the
26 greater likelihood of drier conditions under climate change, the following conclusions can be
27 made. Temperature suitability for native and nonnative fish would be improved and impacts on
28 humpback chub lessened. The overall number of trout is expected to decline, but the number of
29 large trout would be higher than under historic hydrology. The impacts on native vegetation
30 would be less. There would be a greater potential for impacts on cultural resources in both Glen
31 Canyon and Grand Canyon, but an improvement in Tribal values for all metrics evaluated. Most
32 recreation metrics would reflect greater impacts under climate change compared to historic
33 hydrology. There would be a reduction in the value of hydropower generation and capacity.
34
35

36 **4.16.3.2 Alternative B**

37

38 Under Alternative B, total annual average GHG emissions are 55,183,567 MT
39 (60,829,471 tons), which is about 0.011% higher than those under Alternative A. Annual average
40 power generation at Glen Canyon Dam under this alternative is estimated to be about 99.7% of
41 that under Alternative A. However, total annual emissions are slightly higher than those under
42 Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power
43 generation mix for Alternative B being different from that of Alternative A. Consequently, there
44 are negligible differences between Alternatives B and A with regard to their impacts on climate
45 change.

1 **TABLE 4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under Climate**
 2 **Change Compared to Those under Historic Conditions**

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions ^a
Hydrology	
Mean monthly volume and mean daily flow	Decrease in spring and summer, especially for Alternative F, with August being the month with the greatest departure from historic (11–19% reduction in 25th percentile values)
Mean daily change	Increase in July and August, especially for Alternatives A, B, and D (1–17% increase in fluctuating flow alternatives)
Sediment	
Sand load index (bar-building potential)	Increase (2–4%) under Alternatives C–G; decrease (–2 to –3%) for Alternatives A and B
Sand mass balance	Increase (4–9%) under all alternatives
Aquatic ecology	
Temperature suitability—humpback chub	Increase under all alternatives (but especially Alternative F) in upstream reaches (RM 30–119); decrease at RM 157 under Alternatives A, B, and D, and all alternatives (except for Alternative F) at RM 213
Temperature suitability—other native fish	Similar pattern as temperature suitability for humpback chub, but decrease at RM 157 only under Alternatives A and B; all alternatives would have decrease at RM 213
Temperature suitability—coldwater nonnative fish	Increase under all alternatives at RM 0; decrease in all other downstream reaches
Temperature suitability—warmwater nonnative fish	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Temperature suitability—aquatic parasites	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Minimum number of adult humpback chub	Increase (0.2–2%) under all alternatives
Trout catch rate (age 2+, no./hr)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout outmigrants	Increase (0.2–4%) under Alternatives C, D, E, and G; decrease (–1 to –4%) under Alternatives A, B, and F
Trout abundance (age 1+)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout >16 in. total length	Increase (0.4–2%) under Alternatives A, B, C, and F; decrease (–0.1 to –1%) under Alternatives D, E, and G

TABLE 4.16-2 (Cont.)

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions ^a
<i>Riparian vegetation</i>	
Native species diversity and cover (index, higher is better)	Increase (1%) under Alternatives A, B, D, and E; decrease (–0.2 to –1%) under Alternatives C, F, and G
<i>Cultural resources</i>	
Effect of flows on Glen Canyon resources (index, higher is better)	Decrease under all alternatives (–10 to –17%)
Wind transport of sand to protect resources (index, higher is better)	Increase (3–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–1 to –2%)
<i>Tribal values</i>	
Riparian vegetation diversity	Increase (0.2–2%) under all alternatives, but Alternative F (–0.2%)
Marsh index (higher is better)	Increase (1–34%) under all alternatives
Mechanical removal of trout (lower is better)	Increase (2%) under Alternative G; decrease (–6 to –16%) under Alternatives A, B, and D; no removal under Alternatives C, E, and F
TMFs (lower is better)	Decrease (–7 to –17%) under Alternatives B, C, D, E, and G; no TMFs under Alternatives A and F
<i>Recreation</i>	
Camping area index (higher is better)	Increase (4–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–0.02 to –2%)
Fluctuation index (higher is better)	Decrease (–0.1 to –4%) under Alternatives A–E; no change in steady flow Alternatives F and G
Glen Canyon rafting use (number of passenger days lost due to HFES)	Increase (0.1%) under Alternative F; decrease (–0.2 to –8%) under Alternatives A–E and G
Glen Canyon inundation index (higher is better)	Increase (0.5–0.8%) under all alternatives
<i>Hydropower</i>	
Annual net present value of generation	Decrease (–3%) under all alternatives
Net present value of capacity	Decrease (–2 to –4%) under all alternatives

^a These results were obtained by applying the climate weights for each trace shown in Figure 4.16-1 to the modeling results presented in the various resource sections of Chapter 4 (Sections 4.2–4.13).

1 Under Alternative B, the impacts of climate change on sediment resources, humpback
2 chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower
3 would be very similar to those under Alternative A.
4

6 **4.16.3.3 Alternative C**

7
8 Under Alternative C, total annual average GHG emissions are 55,195,829 MT
9 (60,842,987 tons), which is about 0.033% higher than those under Alternative A. Annual average
10 power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of
11 that under Alternative A. However, total annual emissions are slightly higher than those under
12 Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power
13 generation mix for Alternative C being different from that of Alternative A. Consequently, there
14 are negligible differences between Alternatives C and A with regard to their impacts on climate
15 change.
16

17 Under Alternative C, the impacts of climate change on sediment resources would be
18 reduced by climate change resulting in higher Sand Load Index values and an improved sand
19 mass balance. Temperature suitability would be improved, and impacts on humpback chub
20 lessened. The overall number of trout and the number of large trout are expected to be higher
21 than under historic hydrology. The impacts on native vegetation would be slightly greater. There
22 would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower
23 potential in Grand Canyon. There would be an improvement in Tribal values for all metrics
24 evaluated. Most recreation metrics would show improvement under climate change compared to
25 historic hydrology. There would be a reduction in the value of hydropower generation and
26 capacity.
27

29 **4.16.3.4 Alternative D (Preferred Alternative)**

30
31 Under Alternative D, total annual average GHG emissions are 55,200,576 MT
32 (60,848,219 tons), which are about 0.042% higher than those under Alternative A. Annual
33 average power generation at Glen Canyon Dam under this alternative is estimated to be about
34 98.9% of that under Alternative A. Thus, total annual emissions are slightly lower than those
35 under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power
36 generation mix for Alternative D being different from that of Alternative A. Consequently, there
37 are negligible differences between Alternatives D and A with regard to their impacts on climate
38 change.
39

40 Under Alternative D, the impacts of climate change on sediment resources would be
41 reduced by climate change resulting in higher Sand Load Index values and an improved sand
42 mass balance. Temperature suitability would be improved and impacts on humpback chub
43 lessened. The overall number of trout is expected to be higher than under historic hydrology, but
44 the number of large trout would be lower. The impacts on native vegetation would be slightly
45 lower. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a
46 lower potential in Grand Canyon. There would be an improvement in Tribal values for all

1 metrics evaluated. Most recreation metrics would show improvement under climate change
2 compared to historic hydrology. There would be a reduction in the value of hydropower
3 generation and capacity.
4

6 **4.16.3.5 Alternative E**

7
8 Under Alternative E, total annual average GHG emissions are 55,194,171 MT
9 (60,841,159 tons), which are about 0.030% higher than those under Alternative A. Annual
10 average power generation at Glen Canyon Dam under this alternative is estimated to be about
11 99.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those
12 under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power
13 generation mix for Alternative E being different from that of Alternative A. Consequently, there
14 are negligible differences between Alternatives E and A with regard to their impacts on climate
15 change.
16

17 Under Alternative E, the impacts of climate change on sediment resources, humpback
18 chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower
19 would be very similar to those under Alternative D.
20

22 **4.16.3.6 Alternative F**

23
24 Under Alternative F, total annual average GHG emissions are 55,222,189 MT
25 (60,872,044 tons), which are about 0.081% higher than those under Alternative A. Annual
26 average power generation at Glen Canyon Dam under this alternative is estimated to be about
27 98.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those
28 under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power
29 generation mix for Alternative F being different from that of Alternative A. Consequently, there
30 are negligible differences between Alternatives F and A with regard to their impacts on climate
31 change.
32

33 Under Alternative F, the impacts of climate change on sediment resources would be
34 reduced by climate change, resulting in higher Sand Load Index values and an improved sand
35 mass balance. Temperature suitability would be improved and impacts on humpback chub
36 lessened. The overall number of trout is expected to be lower than under historic hydrology, but
37 the number of large trout would be higher. The impacts on native vegetation would be slightly
38 greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but
39 a lower potential in Grand Canyon. There would be an improvement in Tribal values related to
40 marsh vegetation, but a decrease in those related to overall riparian diversity. Most recreation
41 metrics would show improvement under climate change compared to historic hydrology. There
42 would be a reduction in the value of hydropower generation and capacity.
43
44

1 **4.16.3.7 Alternative G**
2

3 Under Alternative G, total annual average GHG emissions are 55,218,627 MT
4 (60,868,117 tons), which are about 0.074% higher than those under Alternative A. Annual
5 average power generation at Glen Canyon Dam under this alternative is estimated to be about
6 98.2% of that under Alternative A. Thus, total annual emissions are slightly lower than those
7 under Alternative A, due to the factors discussed in Section 4.16.2.1. Consequently, there are
8 negligible differences between Alternatives G and A with regard to their impacts on climate
9 change.
10

11 Under Alternative G, the impacts of climate change on sediment resources would be
12 reduced by climate change, resulting in higher Sand Load Index values and an improved sand
13 mass balance. Temperature suitability would be improved and impacts on humpback chub
14 lessened. The overall number of trout, including the number of large trout, is expected to be
15 higher than under historic hydrology. The impacts on native vegetation would be slightly greater.
16 There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower
17 potential in Grand Canyon. There would be an improvement in Tribal values for all metrics
18 evaluated. Most recreation metrics would show improvement under climate change compared to
19 historic hydrology. There would be a reduction in the value of hydropower generation and
20 capacity.
21

22
23 **4.17 CUMULATIVE IMPACTS**
24

25 The CEQ defines a cumulative impact as “the impact on the environment that results
26 from the incremental impact of [an] action when added to other past, present, and reasonably
27 foreseeable future actions, regardless of what agency (federal or nonfederal) or person
28 undertakes such other actions” (40 CFR 1508.7). The assessments summarized in this section
29 place the direct and indirect impacts of the alternatives, presented in the preceding sections of
30 Chapter 4, into a broader context that takes into account the range of impacts of all actions within
31 the Colorado River corridor, from Lake Powell and the Glen Canyon Dam downstream and west
32 to Lake Mead, and the broader Colorado River Basin region (e.g., in the case of climate change).
33

34
35 **4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting**
36 **Cumulative Impacts**
37

38 Past and present (ongoing) actions in the project area have been accounted for in the
39 baseline conditions described for each resource in Chapter 3. Ongoing and reasonably
40 foreseeable future actions considered in the cumulative impact analysis include the projects,
41 programs, and plans of various federal agencies and other entities as described in the following
42 sections. Many of these projects, programs, and plans reflect shared management objectives and
43 cooperation among federal and state agencies, American Indian Tribes, and stakeholders groups
44 that are intended to facilitate more effective and efficient management of the resources in the
45 LTEMP project area. Past, present, and reasonably foreseeable future actions are described in the
46 following sections and summarized in Table 4.17-1.

1 **TABLE 4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable Future Actions and Basin-Wide Trends in**
 2 **the LTEMP Project Area**

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Past and Present (Ongoing) Actions</i>		
Flaming Gorge Dam Operations (Reclamation 2006a)	Flow modifications to achieve more natural flows and temperatures (to preserve and protect fish species) in the Green River, a major tributary of the Colorado River	Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the Green River, a major tributary of the Colorado River, to achieve flows (peak flows, durations, and base flows) and temperature regimes that mimic a more natural hydrograph to protect and recover downstream endangered fish species and their designated critical habitat (Reclamation 2006a).
Aspinall Unit Operations (Reclamation 2012f)	Flow modifications to simulate more natural spring flows and moderate base flows in the lower Gunnison River, a tributary to the Colorado River	The Aspinall Unit consists of Blue Mesa, Morrow Point, and Crystal dams, reservoirs, and powerplants on the Gunnison River, a tributary of the Colorado River. Reclamation published a ROD in 2012 detailing its decision to modify reservoir operations (beginning in 2012) to avoid jeopardizing endangered fish species and their designated critical habitat by allowing higher and more natural downstream spring flows and moderate base flows in the lower Gunnison River. Under the ROD, the Aspinall Unit is operated to meet specific downstream spring peak flow, duration flow, and base flow targets (at the USGS Whitewater gage), as outlined in the project's DEIS preferred alternative. Base flow is maintained to provide adequate fish passage at the Relands Fish Ladder on the Gunnison River near its confluence with the Colorado River.
Interim Guidelines (Reclamation 2007a,b)	Determines the annual volume for release from Glen Canyon Dam through a release tier calculation	The interim guidelines were established for a 20-year period (through 2026) to improve management of the Colorado River by considering water deliveries to Lakes Powell and Mead and to provide more predictability in water supply to users in the Basin states (especially the Lower Basin). They incorporate shortages to increase reservoir storage; coordinated operation of lakes Powell and Mead to minimize shortages in the Lower Basin and avoid the risk of curtailments of use in the Upper Basin; and water conservation in the Lower Basin to increase retention in Lake Mead. The guidelines have improved water supply conditions compared to continued implementation of previous guidelines and criteria; no specific measures to avoid or mitigate minor adverse impacts were identified. Annual volumes may impact recreation economics and water quality in Lake Mead and Lake Powell and water temperatures in the Colorado River; equalization years may increase trout populations below Glen Canyon Dam and increase sandbar erosion. Effects are expected to be independent of the LTEMP alternatives.

4-383

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Past and Present (Ongoing) Actions (Cont.)</i>		
Tamarisk Management and Tributary Restoration (GCNP) (NPS 2002a,b, 2014g)	Reduction of tamarisk trees in the project area Increased diversity of native plant species	The NPS continues its efforts to eradicate tamarisk in the GCNP with the goal of restoring more natural conditions inside the canyons along the Colorado River in the GCNP. Over the past 10 years, the NPS has completed work in 130 project areas, removing more than 275,000 tamarisk trees from over 6,000 ac. Although control methods have been effective, overall return of native diversity has been slow. NPS anticipates overall beneficial effects on native vegetation, soil characteristics, water quality, wetlands, wildlife, wilderness, and visitor experience (NPS 2002b). Adverse impacts are expected to be negligible to minor and short in duration (with the exception of microbiotic soil crusts). No significant adverse effects on threatened, endangered, and sensitive species or ethnographic resources are expected. NPS monitors and mitigates the impacts of tamarisk management on an ongoing basis.
Colorado River Management Plan (NPS 2006b,d)	Established visitor capacity based on size and distribution of campsites Year-round use provides opportunities for a variety of visitor experiences including motorized and non-motorized trips that range from 6 to 25 days	The goal of the CRMP is to protect resources and visitor experience while enhancing recreational opportunities on the Colorado River through the GCNP by establishing visitor capacity based on size and distribution of campsites, overall resource conditions, and visitor experience variables. Recreational use patterns are based on daily, weekly, and seasonal launch limits and seasonal differences in commercial and noncommercial levels. The plan also established a 6.5 month non-motorized season. The actions would have beneficial effects on cultural resource sites, traditional cultural properties, ethnobotanical resources, and other elements important to Tribal assessments of canyon environmental health. Beneficial impacts on commercial operators (revenues and profits) and adjacent lands were also anticipated. Impacts on visitors' use and experience were determined to be negligible to moderate and adverse to beneficial, depending on perspective and desired experience. Adverse impacts on natural resources (biological soil crusts, aquatic resources at attraction sites, special status species, and the soundscape) would range from negligible to major.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Past and Present (Ongoing) Actions (Cont.)</i>		
Backcountry Management Plan (for GCNP) (NPS 1988 ^a)	Allocates and distributes backcountry and wilderness overnight use in campsites along the Colorado River	<p>The goal of the BCMP is to protect and preserve the park’s natural and cultural resources and values and integrity of wilderness character by providing a framework for consistent decision making in managing the park’s backcountry, providing a variety of visitor opportunities and experiences for public enjoyment in a manner consistent with park purposes and preservation of park resources and values and providing for public understanding and support of preserving fundamental resources and values for which Grand Canyon was established.</p> <p>Proposed actions would address both beneficial and adverse effects to: wildlife populations and habitat by minimizing human-caused disturbances and habitat alteration, minimizing impacts to native vegetation, reducing exotic plant species spread, and preserving fundamental biological and physical processes; enhancing wilderness character and values; developing and implementing an adaptive management process that includes monitoring natural, cultural, and experiential resource conditions and responding when resource degradation has resulted from use levels; preserving and protecting natural soil conditions by minimizing impacts to soils from backcountry recreational activities; minimizing adverse chemical, physical, and biological changes to water quality in tributaries, seeps, and springs; and preserving cultural resource integrity and condition.</p>

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Past and Present (Ongoing) Actions (Cont.)</i>		
Abandoned Mine Lands Closure Plan (NPS 2010b)	Closure of mine openings	<p>The NPS will address health and safety hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at 16 AMLs in GCNP. Closure of mine openings^b would have a long-term beneficial impact on historic structures by protecting mine features from vandalism; however, impacts associated with closure construction activities (installing gates, grates, or cupolas or moving earth, rocks, or tailings piles), while localized, would range from negligible to mostly minor, with some possible moderate adverse (i.e., measurable and perceptible) effects. Beneficial impacts would also be expected on bats and other wildlife by providing protection from disturbance, although NPS notes that closure construction could have minor long-term adverse effects, especially to other wildlife that use the openings for nesting, denning, or shade (effects would be partially mitigated by avoiding closing mine features that are used by a listed species).</p> <p>Because several AML sites are located near trails and river access points in GCNP, they are easily accessible by visitors (although no safety incidents have been documented). Impacts of AML closure, therefore, are expected to be beneficial overall because they would reduce the likelihood of injury from visitor access. Visitors wishing to experience bats and other wildlife, however, may incur localized short-term negligible to minor adverse effects (especially during closure construction when small areas would be closed to visitors). NPS notes that other sites would remain open to visitors, thus affording other opportunities to experience bats and wildlife and mitigating these impacts.</p>
Fire Management Plan (GCNP) (NPS 2012f)	Reduction of wildfire risk in GCNP Ecosystem Restoration	<p>The NPS manages wildland fire risk in GCNP using an adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels reduction, community assistance, and accountability. Implementation of the plan meets the park goals and objectives for managing park resources and visitor experiences, as identified in the General Management Plan (NPS 1995). It also supports the objects of the Resource Management Plan (NPS 1997). This plan may have beneficial or adverse impacts related to fire reduction, such as decreased runoff of sediments, decreased flooding, maintaining or restoring habitat in uplands.</p>

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Past and Present (Ongoing) Actions (Cont.)</i>		
Uranium Mining and Public Lands Withdrawal (DOI 2012b)	Withdrawal of federal lands in the Grand Canyon region from location and entry Continued exploration and mining on state and private lands	<p>In January 2012, the Bureau of Land Management (BLM) withdrew from location and entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern Arizona for a 20-year period. The purpose of the land withdrawal is to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse effects related to locatable mineral exploration and development (i.e., uranium mining). It would have no effect on the exploration and development of any non-federal lands within its exterior boundaries; the withdrawal area would remain available for the development of federal leasable and salable minerals. Active exploration for uranium on state and private lands in the region would not be affected by the withdrawal.</p> <p>Potential impacts of uranium mining are currently difficult to quantify because of the uncertainties of subsurface water movement, radionuclide migration, and biological exposure pathways. Based on its study of groundwater near historic uranium mining sites in northern Arizona, the USGS concluded the likelihood of adverse impacts on water resources (from water use and degradation or impairment) is likely to be low, but if water resources were affected, the risk to the greater ecosystem, Tribes, and tourists could be significant (Bills et al. 2010; DOI 2012b).</p>
Comprehensive Fisheries Management Plan (below Glen Canyon Dam) (NPS 2013e)	Potential stocking of sterile rainbow trout in Lees Ferry Translocation of native fish species Removal of high-risk nonnative fish from areas important for native fish Beneficial use of all nonnative fish removed Implementation of an experimental adaptive strategy for evaluating the suitability of razorback sucker in western portions of the Grand Canyon	<p>The main purpose of the plan is to maintain a thriving native fish community within GCNP while also maintaining a highly valued recreational trout fishery community in the Glen Canyon reach. The actions would have a beneficial effect on native and endangered fish populations, as well as visitor experience (by avoiding quality decline of the rainbow trout fishery), and no significant adverse effect on public health, public safety, or threatened or endangered species. They would, however, contribute to long-term ethnographic resource cumulative impacts resulting from fish management (specifically euthanizing fish), which constitutes an adverse effect under Section 106 of the NHPA. This effect would be mitigated to the extent possible through an MOA between the NPS, SHPO, and Tribes (NPS 2013h).</p>
Lower Colorado River Multi-Species Conservation Program (DOI 2005)	Management of take permits (while conserving critical habitat and protecting threatened and endangered species)	<p>The program is a cooperative species conservation effort between federal and non-federal entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water diversions and power production while optimizing opportunities for future water and power development and to provide the basis for incidental take permits while conserving critical habitat and working toward the recovery of threatened and endangered species. Potential beneficial impacts to special status species in Lower Basin.</p>

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Reasonably Foreseeable Future Actions</i>		
Special Flight Rules in the Vicinity of GCNP, AZ (14 CFR Part 93, Subpart U)	Reduction of noise in GCNP	Rules to be established to substantially restore natural quiet at GCNP in accordance with the National Parks Overflights Act of 1987 (PL 100-91). Would establish a system of routes, altitudes, flight allocations and flight free zones in the air space in and around GCNP.
Lake Powell Pipeline Project (UBWR 2015)	Construction/operation of pipeline and penstock Construction/operation of hydropower stations Construction/operation of transmission lines Increased water withdrawal from Lake Powell (adjacent to Glen Canyon Dam)	The Utah State legislature has authorized the UBWR to build a pipeline to transfer water from Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in southwestern Utah. The proposed pipeline is currently being evaluated for potential effects on water storage in Lake Powell and related resources, the availability of water for downstream users, habitat conditions, and aquatic species and resources, including sport fisheries (UBWR 2011a,b).
Grand Canyon Escalade (Confluence Partners, LLC 2012a)	Construction/operation of multiple elements (tramway, riverwalk, road, parking lots, and buildings) Increased visitor foot and motorized traffic Increased jobs and gross revenues (to the Navajo Nation)	The Navajo Nation has proposed the 420-ac development project on the Grand Canyon’s eastern rim, on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking lots. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in beneficial impacts to the local economy through increased tourism and job creation.
Red Gap Ranch Pipeline (City of Flagstaff City Council 2013)	Increased groundwater withdrawal from the C-aquifer on the Coconino Plateau Construction/operation of multiple elements (wells, roads, pipelines, and a treatment facility)	In anticipation of a future water supply shortfall, the City of Flagstaff has purchased property on the Red Gap Ranch on which it plans to develop new municipal wells to augment its current supply. The wells would withdraw up to 8,000 acre-feet of groundwater each year from the C-aquifer on the Coconino Plateau. A NEPA review, currently underway, is evaluating the impacts of groundwater withdrawal from the aquifer on base flow feeding the Little Colorado River, Clear Creek, and Chevelon Creek, which ultimately flow into the Colorado River. It is also evaluating the impacts of groundwater conveyance on biological and cultural resources on the Red Gap Ranch property.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Reasonably Foreseeable Future Actions (Cont.)</i>		
Page-LeChee Water Supply Project (NPS 2009b)	Construction/operation of water intakes and pumping station Construction/operation of a conveyance pipeline Increased water withdrawal from Lake Powell (in the Chains area)	The Page-LeChee would improve the existing water supply system for the city of Page and the LeChee Chapter of the Navajo Nation. It would increase the capacity of water already drawn from Lake Powell; it would include water intakes, a pumping station, and a conveyance pipeline located on the GCNRA.
Four Corners Power Plant (FCPP) and Navajo Mine Energy Project (OSMRE 2015a, b)	Reduced NO _x and PM pollutants emissions	The FCPP, located just north Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), consists of five pulverized coal-burning steam electric generating units with a total generating capability of 2,100 MW and other ancillary facilities. The proposed lease amendment would extend the life of the powerplant to 2041. Under the proposed alternatives, air emissions would not exceed NAAQS and deposition impacts with 50 km (31 mi) of the FCPP are expected to be negligible. The Arizona Public Service Company plans to close three units (Units 1, 2, and 3) and install SCR controls on the remaining two units (Units 4 and 5) to reduce NO _x and PM pollutants that contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas, including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b).
Clean Power Plan Proposed Rule (EPA 2014b)	Reduced CO ₂ emissions	The Clean Power Plan Proposed Rule would reduce atmospheric carbon by limiting the CO ₂ emissions from existing fossil-fuel fired powerplants in the United States. The draft plan would establish state-by-state carbon emissions rate reduction targets with the aim of reducing emissions from the power sector to about 30% below 2005 levels by 2030 (EPA 2014b). The EIA (2015) estimates the proposed rule would result in a reduction of U.S. power sector CO ₂ emissions to about 1,500 million MT/yr by 2025 (levels not seen since the early 1980s). The plan is expected to be finalized in 2015.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
<i>Human Activities Affecting Climate</i>		
	Increased temperatures (air and surface water)	The southwest is already experiencing the effects of climate change, with the decade from 2001 to 2010 being the warmest on record (Garfin et al. 2014; World Meteorological Organization 2014; NAS 2007). Precipitation trends are more variable across the region, but drought-induced water shortages in the Colorado River Basin are a growing concern. Changes in temperature and precipitation patterns could take a toll on the diversity of plant and animal species (e.g., widespread loss of trees due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and an increased risk of heat stress and disruption to electric power generation. The recreational economy could also be affected by a shorter snow season and reduced streamflow (Garfin et al. 2014).
	Increased variability in precipitation and stream flows	
	Drought conditions and water loss (through evaporation and evapotranspiration)	
	Increased risk of wildfires	
	Decreased snowpack and stream flows (due to less late winter precipitation and snowpack sublimation)	
	Seasonal shifts in snowmelt and high stream flows (to earlier in the year)	
	Increased flooding potential (due to earlier snowmelt)	
	Decreased spring and summer runoff (due to decreased snowpack)	
	Lowered lake levels (Lakes Powell and Mead)	
	Increased agricultural water demand (due to increased temperatures)	
	Reduced agricultural yields	
	Insect outbreaks	
	Increased wildfires	
	Reduced plant and animal diversity (widespread tree mortality)	
	Heat threats to human health	

^a New BCMP expected to be implemented with ROD in 2016.

^b NPS notes that except for backfilling, most closure types would be reversible, thereby reducing the impacts of closure on those sites eligible for the *National Register* (NPS 2010b).

1 **4.17.1.1 Past and Present (Ongoing) Actions**
2

3 There are numerous actions documented in decisions, plans, policies, and initiatives that
4 relate directly or indirectly to the operation of Glen Canyon Dam and management of the
5 Colorado River ecosystem (see Section 1.10). These actions are listed below, and establish the
6 current conditions or baseline for the LTEMP.
7

8
9 **Flaming Gorge Dam Operations**
10

11 Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the
12 Green River, a major tributary of the Colorado River upstream of Lake Powell, to achieve flows
13 (peak flows, durations, and base flows) and temperature regimes that mimic a more natural
14 hydrograph to protect and recover downstream endangered fish species and their designated
15 critical habitat (Reclamation 2006a).
16

17
18 **Aspinall Unit Operations**
19

20 The Aspinall Unit, managed and operated by Reclamation (in cooperation with various
21 other federal agencies), consists of Blue Mesa, Morrow Point, and Crystal Dams, Reservoirs, and
22 Powerplants on the Gunnison River, a tributary of the Colorado River upstream of Lake Powell.
23 It was originally authorized by the Colorado River Storage Project Act of 1956. In 2012,
24 Reclamation published a Record of Decision (ROD) that details the decision to modify reservoir
25 operations (beginning in 2012) to avoid jeopardizing endangered fish species and their
26 designated critical habitat by allowing higher and more natural downstream spring flows and
27 moderate base flows in the lower Gunnison River (Reclamation 2012g).
28

29
30 **Interim Guidelines for Coordinated Operation of Lake Powell and Lake Mead**
31

32 Management of the Colorado River system must adhere to the various treaties, decrees,
33 statutes, regulations, contracts, and agreements that are collectively known as the Law of the
34 River (Table 1-2). The Law of the River applies mainly to the allocation, appropriation,
35 development, and exportation of the waters within the Colorado River Basin
36 (Reclamation 2012a). In 2007, Reclamation (in cooperation with the Bureau of Indian Affairs
37 [BIA], U.S. Fish and Wildlife Service [FWS], NPS, Western, and the United States Section of
38 the International Boundary and Water Commission) completed an EIS and ROD to propose and
39 adopt specific interim guidelines to address water shortages for the Colorado River Lower Basin
40 and to coordinate operations for Lakes Powell and Mead, especially under drought and low
41 reservoir conditions. These guidelines were established for a 20-year period, which would extend
42 through 2026. The objectives of the interim guidelines are to (1) improve Reclamation's
43 management of the river by considering the effects of water deliveries to Lakes Powell and Mead
44 on water storage and supply, power production, recreation, and other resources; (2) provide users
45 of Colorado River water, especially those in the Lower Basin states, more predictability in future
46 water deliveries, especially during drought and low-reservoir conditions; and (3) provide other

1 mechanisms of storage and delivery of water supplies in Lake Mead to increase the flexibility in
2 meeting water use needs in the Lower Basin states. In addition, the interim guidelines require the
3 Basin states to address future controversies through consultation and negotiation before resorting
4 to litigation (Reclamation 2007a,b).

5
6 Drought conditions in the Colorado River Basin between 2000 and 2007, coupled with
7 increased demands for Colorado River water supplies, resulted in decreased reservoir storage in
8 the basin from 55.8 million ac-ft in 1999 (94% of capacity) to 32.1 million ac-ft in 2007 (54% of
9 capacity). The interim guidelines incorporate three main elements: (1) shortages to conserve
10 reservoir storage; (2) coordinated operation of Lakes Powell and Mead on the basis of specified
11 reservoir conditions to minimize shortages in the Lower Basin and avoid the risk of curtailments
12 of use in the Upper Basin; and (3) water conservation in the Lower Basin to increase retention
13 of water in Lake Mead. The interim guidelines presented in Section XI of the ROD
14 (Reclamation 2007b) define “normal conditions” in Lake Mead as lake levels above elevation
15 1,075 ft AMSL and below elevation 1,145 ft AMSL. They quantify surplus and shortage
16 conditions against these levels and define apportionments to Lower Basin states on this basis.

17
18
19 **Tamarisk Management and Tributary Restoration Project at Grand Canyon**
20 **National Park**

21
22 The NPS continues its efforts to eradicate tamarisk in side canyons, tributaries, developed
23 areas, and springs above the pre-dam water level in GCNP (NPS 2002a,b, 2014g). Tamarisk is a
24 nonnative shrub that was introduced to the United States in the 19th century as an erosion control
25 agent. Since its introduction, the plant has spread throughout the west and has caused major
26 changes to natural ecosystems. The shrub reached the GCNP in the 1920s and by the time Glen
27 Canyon Dam was completed in 1963, it had become a dominant riparian zone species along the
28 Colorado River. The NPS’s ongoing goal is to restore more natural conditions inside canyons
29 along the river in GCNP and to prevent further loss or degradation of existing native biota. To
30 this end, restoration biologists use an adaptive strategy to manage and control tamarisk in the
31 GCNP. Control measures involve a combination of mechanical and chemical methods tailored to
32 site-specific conditions and plant size. These include pulling, cutting to stump level, applying
33 herbicide, and girdling (leaving the dead tree in place for wildlife habitat) (NPS 2014g).

34
35 The tamarisk leaf beetle (*Diorhabda* spp.) was not intentionally introduced, but was
36 discovered in 2009 near Navajo Bridge and at RM 12, and at several locations, including
37 Lees Ferry, in 2010. It is currently found throughout Glen and Grand Canyons (Section 3.6.2).
38 The beetle causes early and repeated defoliation of tamarisk, eventually resulting in mortality.
39 Although the beetle has been associated with widespread defoliation of some tamarisk
40 communities along the river, its long-term effects on tamarisk abundance and distribution in
41 Glen and Grand Canyons is not currently known.

1 **Colorado River Management**
2

3 The CRMP specifies the actions that NPS follows to protect resources and visitor
4 experience while enhancing recreational opportunities on the Colorado River through GCNP
5 (NPS 2006a,b). The CRMP describes management goals for two geographic sections of the
6 Colorado River: (1) Lees Ferry to Diamond Creek, and (2) Diamond Creek to Lake Mead. The
7 selected action for the Lees Ferry to Diamond Creek section (RM 0 to 226) defines mixed
8 motor/no motor seasons and reduces the maximum group size for commercial groups. It
9 establishes use patterns based on daily, weekly, and seasonal launch limits, provides year-round
10 noncommercial use and a 6.5 month non-motorized use period during the shoulder and winter
11 seasons. Management of the Lower Gorges section from Diamond Creek to Lake Mead (RM 226
12 to 277) involves cooperation between the NPS and the Hualapai Tribe, and provides
13 opportunities for shorter whitewater and smoothwater trips (NPS 2006b).
14
15

16 **Backcountry Management Plan**
17

18 The Backcountry Management Plan defines the concepts, policies, and operational
19 guidelines NPS follows to manage visitor use and protect natural resources in the backcountry
20 and wilderness areas of the GCNP (NPS 1988). The objectives of the Backcountry Management
21 Plan are to provide a variety of backcountry recreational visitor opportunities that are compatible
22 with resource protection and visitor safety. The plan supports the objectives of the CRMP and is
23 currently undergoing revision. A Draft EIS on the proposed plan was recently issued
24 (NPS 2015b).
25
26

27 **Abandoned Mine Lands Closure Plan**
28

29 In 2010, the NPS finalized an EA that evaluated methods to correct health and safety
30 hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at
31 16 abandoned mine lands (AMLs) in GCNP (NPS 2010b). The resources affected by AML
32 closure are historic structures (mine features such as adits, shafts, and cairns, among others) and
33 districts, bats and other wildlife (including federally listed species and species of management
34 concern), visitor experience (including health and safety), and wilderness.
35
36

37 **Fire Management at Grand Canyon National Park**
38

39 The NPS manages wildland fire risk in GCNP through its Fire Management Program, as
40 detailed in its Fire Management Plan (NPS 2012d). The Fire Management Plan employs an
41 adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels
42 reduction, community assistance, and accountability. Implementation of the plan meets the park
43 goals and objectives for managing park resources and visitor experiences, as identified in the
44 General Management Plan (NPS 1995). The Fire Management Plan also supports the objectives
45 of the Resource Management Plan (NPS 1997). These include protecting human health and
46 safety and private and public property; restoring and maintaining park ecosystems in a natural

1 and resilient condition; interpreting and educating Tribes, stakeholders, and the public about the
2 importance of the natural fire regime; and promoting a science-based program that relies on
3 current and best-available information, as described in Table 3.2 of NPS (1995).
4

6 **Uranium Mining and the Northern Arizona Withdrawal of Public Lands**

7

8 Uranium mineralization in the Grand Canyon region is associated with geologic features
9 called breccia pipes. A breccia pipe is a cylindrical, vertical mass of broken rock (breccia) that
10 typically measures tens of meters across and hundreds of meters vertically. There are
11 1,300 known or suspected breccia pipes in the Grand Canyon region (Spencer and
12 Wenrich 2011). Development of uranium minerals associated with breccia pipes dates back to
13 the 1940s. By the late 1980s, more than 71 breccia pipes had been found to contain ore-grade
14 rock (DOI 2012b). As of 2010, over 23 million lb of uranium (U_3O_8) had been produced from
15 nine breccia pipes (Spencer and Wenrich 2011); the estimated mean undiscovered uranium
16 endowment for the region is about 933.6 million lb (Otton and Van Gosen 2010)
17

18 In January 2012, the Bureau of Land Management (BLM) withdrew from location and
19 entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern
20 Arizona for a 20-year period (DOI 2012b). The withdrawal includes 684,449 ac of federal land
21 administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land
22 administered by the USFS south of GCNP (South Parcel). The purpose of the land withdrawal is
23 to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse
24 effects related to locatable mineral exploration and development (i.e., uranium mining). The
25 withdrawal would have no effect on the exploration and development of any non-federal lands
26 within its exterior boundaries (with the exception of about 23,993 ac of split estate lands where
27 locatable minerals are owned by the federal government), and the withdrawal area would remain
28 available for the development of federal leasable and salable minerals (e.g., oil and gas leases
29 and sand and gravel permits). The public land laws would still apply (DOI 2012b).
30

31 Although 3,156 mining claims predate BLM's notice of withdrawal in 2009, most of
32 these did not have valid existing rights at the time of the notice and, therefore, cannot be
33 developed during the withdrawal period. The BLM estimates that 11 mines, including four
34 existing uranium mines, could still be developed under the full withdrawal, a level similar to that
35 in the 1980s when the high price of uranium spurred interest in mining (DOI 2012b). Arizona
36 State land parcels and private lands in the region could also be developed (NPS 2013k). Thus,
37 uranium mining, while reduced, will continue throughout the withdrawal period.
38

39 Active exploration for uranium in the region is currently focused on state and private
40 lands located within the Cataract Canyon/Havasu Creek surface and groundwater basins, to the
41 south of GCNP. These lands are adjacent to the Havasupai Reservation, Hualapai Reservation,
42 and the Kaibab National Forest, and are operated near the Boquillas Ranch and other private
43 lands owned by the Navajo Nation (NPS 2013k).
44
45

1 **Comprehensive Fisheries Management below Glen Canyon Dam**
2

3 The NPS is implementing its Comprehensive Fisheries Management Plan for all fish-
4 bearing waters in GCNP and GCNRA below Glen Canyon Dam. The plan was developed in
5 coordination with the Arizona Game and Fish Department, the FWS, Reclamation, and the
6 USGS GCMRC; its purpose is to maintain a thriving native fish community within GCNP, while
7 also maintaining a highly valued recreational trout fishery in the Glen Canyon reach, defined as
8 the 16.5 mi of river downstream from Glen Canyon Dam on the Colorado River in the GCNRA,
9 including Lees Ferry and the mouth of the Paria River (NPS 2013e).

10
11 The Plan’s actions include stocking sterile rainbow trout in Lees Ferry (when there are
12 fishery declines); translocation of native fish species, including the humpback chub; removal of
13 high-risk nonnative fish from selected areas important for native fish; beneficial use of all
14 nonnative fish removed; and the implementation of an experimental adaptive strategy to evaluate
15 the suitability of razorback sucker in western portions of the Grand Canyon (NPS 2013h).

16
17
18 **Lower Colorado River Multi-Species Conservation Program**
19

20 The Lower Colorado River Multi-Species Conservation Program (LCRMSCP)
21 implements and coordinates the Secretary of the Interior’s statutory responsibilities under the
22 ESA (DOI 2005). The program is a cooperative species conservation effort between six federal
23 agencies (Reclamation, BIA, NPS, BLM, Western, and the FWS) and numerous non-federal
24 entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water
25 diversions and power production while optimizing opportunities for future water and power
26 development (lead agency: Reclamation) and to provide the basis for incidental take permits
27 (lead agency FWS) while conserving critical habitat and working toward the recovery of
28 threatened and endangered species as well as reducing the likelihood of additional species being
29 listed. Measures to mitigate the impacts of the incidental take of species covered under the
30 Program are contained in its Habitat Conservation Plan (LCRMSCP 2004). The Habitat
31 Conservation Plan and other program information are available at
32 <http://www.lcrmscp.gov/index.html>.

33
34
35 **4.17.1.2 Reasonably Foreseeable Future Actions**
36
37

38 **Special Flight Rules in the Vicinity of Grand Canyon National Park**
39

40 The NPS will establish new rules to substantially restore natural quiet at GCNP in
41 accordance with the National Parks Overflights Act of 1987 (P.L. 100-91). The rules would
42 create a system of routes, altitudes, flight allocations, and flight-free zones in the air space in and
43 around GCNP.
44
45

1 **Lake Powell Pipeline Project**
2

3 In 2006, the Utah State legislature passed the Lake Powell Pipeline Development Act to
4 authorize the Utah Board of Water Resources (UBWR) to build a pipeline to transfer water from
5 Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in
6 southwestern Utah. The proposed project would consist of (1) building and operating 139 mi of
7 69-in. diameter pipeline and penstock, 35 mi of 30-in. to 48-in. diameter pipeline, and 6 mi of
8 24-in. diameter pipeline; (2) a combined conventional peaking and pumped storage hydropower
9 station; (3) five conventional in-pipeline (booster) hydropower stations; and (4) transmission
10 lines. The booster pumping stations along the length of the pipeline would provide the 2,000-ft
11 lift needed to move the water over the high point within the Grand Staircase-Escalante National
12 Monument. From the high point, water would flow through a series of hydroelectric turbines to
13 make use of the 2,900-ft drop in elevation from the high point to the end of the pipeline in
14 St. George (UBWR 2015; FERC 2011). The Lake Powell intake would be located near the south
15 end of the lake adjacent to Glen Canyon Dam (UBWR 2011a). UBWR plans to have its licenses,
16 permits, and ROD issued sometime in 2015 so construction can begin in 2020 (water delivery
17 would not begin until 2025) (UBWR 2015).
18
19

20 **Grand Canyon Escalade**
21

22 Private developers have proposed to the Navajo Nation, a 420-ac development project,
23 known as the Grand Canyon Escalade, on the Grand Canyon’s eastern rim on the western edge
24 of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The
25 development would include a 1.4-mi-long, eight-person tramway (gondola) to transport visitors
26 3,200 ft from the rim to the canyon floor. On the rim, the development would include retail
27 shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with
28 patio, roads, and parking for cars and RVs. It would also include a restaurant, gift shops, an
29 amphitheater, and a riverwalk (with an elevated walkway) along the canyon floor. Analysis for
30 this project has not been conducted, so impacts have not been fully determined; however, the
31 construction and operation of the Escalade project could result in adverse impacts on natural and
32 cultural resources in the areas of the Little Colorado River confluence, wilderness, visual
33 resources, and resources of importance to multiple Tribes. It could also result in beneficial
34 impacts to the local economy through increased tourism and job creation.
35
36

37 **Red Gap Ranch Pipeline**
38

39 In 2006, Reclamation completed a study that projected a water supply shortfall of about
40 3,370 acre-feet/year for the City of Flagstaff (and other towns in Coconino County) by the
41 year 2050 (Reclamation 2006b). To address its shortfall, the City of Flagstaff has purchased
42 property on the Red Gap Ranch (about 34 mi to the east), on which it plans to develop new
43 municipal wells to augment its current supply. The wells would withdraw up to 8,000 acre-feet
44 of groundwater each year from the C-aquifer (on the Coconino Plateau) and send it via pipeline
45 to the City (City of Flagstaff City Council 2013). Because the pipeline crosses federal land and is
46 partially funded with federal dollars, the proposed project is currently undergoing a NEPA

1 review (EA). The scope of the EA is to evaluate the impacts of groundwater withdrawal on the
2 base flow that feeds the Little Colorado River, Clear Creek, and Chevelon Creek (which
3 ultimately feed the Colorado River), as well as the impacts the conveyance of groundwater
4 (including the construction of pipelines, roads, and a treatment facility) could have on biological
5 and cultural resources on the Red Gap Ranch property.
6
7

8 **Page-LeChee Water Supply Project**

9

10 The Page-LeChee water supply project is a water supply facility providing domestic
11 water supply for the city of Page and the LeChee Chapter of the Navajo Nation (NPS 2009b).
12 The proposed project would improve the existing system (consisting of three pumps operating at
13 3,050 gpm) and increase the capacity of water already drawn from Lake Powell; it would include
14 water intakes, a pumping station, and a conveyance pipeline located on the GCNRA (from Lake
15 Powell to a tie-in point on the existing system near U.S. 89 between the Glen Canyon rim and the
16 water treatment plant in Page).
17
18

19 **Four Corners Power Plant and Navajo Mine Energy Project**

20

21 The Office of Surface Mining Reclamation and Enforcement (OSMRE) has completed a
22 final EIS for the lease amendment with the Navajo Nation that would extend the life of the Four
23 Corners Power Plant (FCPP) to 2041 (OSMRE 2015a, b). The FCPP, located just north
24 Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), consists of five pulverized
25 coal-burning steam electric generating units with a total generating capability of 2,100 MW and
26 other ancillary facilities, including Morgan Lake and Morgan Lake Dam, fly ash storage silos
27 and bottom ash dewatering bins, three switchyards, an intake canal, and access road
28 (OSMRE 2015b). As part of the proposed action, the Arizona Public Service Company would
29 close three units (Units 1, 2, and 3) and install selective catalytic reduction (SCR) controls on the
30 remaining two units (Units 4 and 5) to reduce NO_x and particulate matter (PM) pollutants that
31 contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas,
32 including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b). The
33 proposed action would also include the renewal of the transmission line right-of-way that
34 connects the powerplant to the power grids in Arizona and New Mexico and the development of
35 a new 5,600-ac mine area, the Pinabete Mine Permit area, to supply coal to the powerplant for up
36 to 25 years (beginning July, 2016). The Pinabete Mine area is a surface coal mining and
37 reclamation operation located near the existing Navajo Mine in San Juan County, New Mexico
38 (OSMRE 2015c).
39
40

41 **EPA's Clean Power Plan Proposed Rule for Existing Powerplants**

42

43 The Clean Power Plan Proposed Rule is being developed by the U.S. Environmental
44 Protection Agency (EPA) under Section 111(d) of the Clean Air Act (CAA) to reduce
45 atmospheric carbon by limiting the CO₂ emissions from existing fossil-fuel fired powerplants in
46 the United States. The final plan, released in October 2015, establishes state-by-state carbon
47 emissions rate reduction targets with the aim of reducing emissions from the power sector to

1 about 30% below 2005 levels by 2030 (EPA 2014b, 2015c). The EIA (2015) estimates the
2 proposed rule would result in a reduction of power sector CO₂ emissions to about 1,500 million
3 MT/yr by 2025, levels not seen since the early 1980s. The plan is expected to be finalized in
4 2015.

7 **4.17.2 Climate-Related Changes**

9 The southwest is already experiencing the effects of climate change (Garfin et al. 2014).
10 The decade from 2001 to 2010 was the warmest on record, with temperatures almost 1.1°C
11 higher than historic averages (Garfin et al. 2014; World Meteorological Organization 2014).
12 Precipitation trends are more variable across the region, but drought-induced water shortages in
13 the Colorado River Basin are a growing concern, prompting federal and state agencies, Tribes,
14 and other stakeholders to develop adaptation and mitigation strategies to address imbalances
15 between water supply and demand in the coming years (Garfin et al. 2014; NAS 2007;
16 Reclamation 2007b, 2012c). Section 4.16 provides a discussion of climate change as related
17 to the LTEMP.

19 Higher temperatures in the Colorado River Basin have resulted in less precipitation
20 falling and being stored as snow at high elevations in the Upper Basin (the main source of runoff
21 to the river), increased evaporative losses, and a shift in the timing of peak spring snowmelt
22 (and high streamflow) to earlier in the year (NAS 2007; Christensen et al. 2004; Jacobs 2011).
23 These effects in turn have exacerbated competition among users (farmers, energy producers,
24 urban dwellers), as well as effects on ecological systems, during a time when due to a rapidly
25 rising population water demand has never been higher (Garfin et al. 2014). The combination of
26 decreasing supply and increasing demand will present a challenge in meeting the water delivery
27 commitments outlined in the Colorado River Compact of 1922 (apportioning water between the
28 Upper and Lower Basins) and the United States–Mexico Treaty of 1944 (which guarantees an
29 annual flow of at least 1.5 million ac-ft to Mexico). In 2007, DOI adopted interim guidelines
30 (Reclamation 2007b) to specify modifications to the apportionments to the Lower Basin states in
31 the event of water shortage conditions (see section above).

33 Changes in temperature and precipitation patterns attributed to climate change could also
34 take a toll on the region’s rich diversity of plant and animal species (e.g., widespread loss of trees
35 due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and
36 an increased risk of heat stress and disruption to electric power generation (during summer heat
37 waves). The recreational economy could also be affected by a shorter snow season and reduced
38 streamflow (Garfin et al. 2014). Such effects are likely to continue well into the foreseeable
39 future (NAS 2007).

42 **4.17.3 Cumulative Impacts Summary by Resource**

44 The following sections discuss the past, present, and reasonably foreseeable future
45 actions, including the LTEMP alternatives, that could contribute to cumulative impacts on
46 resources within the project area. Table 4.17-2 provides a summary of these contributions by
47 resource area.

1 **TABLE 4.17-2 Summary of Cumulative Impacts and Incremental Contributions under LTEMP Alternatives**

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Water Resources	Colorado River between Glen Canyon Dam and Lake Mead; lakes Powell and Mead	Projected future changes in flow due to increased water demand (as a result of population growth and development), and decreased water supply, drought, and increased water temperature attributed to climate change could be the greatest contributors to adverse impacts on Colorado River flows, storage in lakes Powell and Mead, and water quality (temperature and salinity). The 2007 Interim Guidelines are improving water supply conditions through increased water conservation efforts, which should provide more predictability in water supply to users in the Basin States (especially the Lower Basin). They are also improving water temperature and water quality in lakes Powell and Mead.	The proposed action is consistent with the 2007 Interim Guidelines for annual water deliveries. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions. With the exception of Alternative B, the LTEMP alternatives would result in slightly greater summer warming and a slightly increased potential for bacteria and pathogens along shorelines.
Sediment Resources	Colorado River between Glen Canyon Dam and Lake Mead; inflow deltas in lake Mead	Potential future hydrology in the Colorado River (as determined by the 2007 Interim Guidelines), including the effects of climate change, could affect tributary sediment delivery (supply), fine sediment transport, sandbar formation, and lake delta formation over the long term. Glen Canyon Dam and Lake Powell trap most of the mainstem Colorado River sediment supply (post-dam sediment supplies less than 10% of the pre-dam supply). Implementation of HFEs could result in an improvement in sandbar building.	LTEMP alternatives are expected to improve sediment conditions to varying degrees by conserving sediment and building sandbars at higher elevations. Alternatives with the most HFEs (Alternatives C, D, E, F, and G) have the highest sandbar building potential. Alternative A has the lowest sandbar building potential. The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

4-399

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Natural Processes	Colorado River ecosystem in Glen, Marble, and Grand Canyons	Projected future changes in flow due to increased water demand (as a result of population growth and development) and decreased water supply (and sediment supply), drought, and increased water temperature attributed to climate change would contribute to adverse impacts on natural processes through changes in Colorado River flows, sediment supply, and temperature. Implementation of HFES could result in an improvement in sandbar building.	Compared to Alternative A, Alternatives C, D, F, and G are expected to increase sediment conservation, increase the stability of nearshore habitats, and provide slightly warmer water temperatures. The proposed actions contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Aquatic Ecology	Colorado River between Glen Canyon Dam and Lake Mead	<p>Aquatic resources would be affected by changes in flow due to increased water demand (as a result of population growth and development); decreased water supply, drought, and increased water temperature attributed to climate change; and other foreseeable actions (related to fish management and uranium mining). Drought conditions (and actions such as the Lake Powell pipeline project) would result in lower reservoir elevations and benefits to aquatic resources associated with warmer release temperatures. Warmer water temperatures, however, could also result in adverse effects if they increase the distribution of nonnative species adapted to warm water (e.g., fish parasites). 2007 Interim Guidelines determine annual volume and equalization years may increase trout production and river temperature both of which may impact HBC populations.</p> <p>Translocation of native fish species (humpback chub) from the Little Colorado River to other tributaries within the Grand Canyon would have a beneficial (protective) impact on aquatic resources.</p>	Alternatives with higher fluctuation levels (Alternatives B and E) have lower trout numbers and slightly higher humpback chub numbers, but less nearshore habitat stability and aquatic productivity. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Vegetation	Riparian zone along the Colorado River between Glen Canyon Dam and Lake Mead	<p>Lower regional precipitation with climate change would result in a shift to more drought-tolerant species in the New High Water Zone; those in the Old High Water Zone would continue to decline. Drought conditions would favor nonnative tamarisk (which is tolerant of drought stress). However, tamarisk control efforts by the NPS and possibly the effects of the tamarisk leaf beetle and splendid tamarisk weevil would increase tamarisk mortality and improve conditions for native shrubs over time.</p> <p>Feral burros contribute to impacts on riparian vegetation in the Old High Water Zone (by reducing vegetation and decreasing species diversity); recreational visitors may also contribute to vegetation loss and the introduction of exotic plant species.</p>	<p>Most alternatives, including Alternative A, result in a decrease in native community cover and wetlands. Alternative D is the only alternative that results in an overall improvement in vegetation. The program’s contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.</p>
Wildlife	Colorado River corridor between Glen Canyon Dam and Lake Mead	<p>Cumulative impacts on aquatic resources and riparian vegetation (as described in the above entries) affect riparian and terrestrial wildlife. Wildlife may also be affected by other future actions and basin-wide trends. Increased water demand and lower flows downstream of Glen Canyon Dam could stress riparian and wetland vegetation, affecting both wildlife habitats and the wildlife prey base. Warmer discharges (attributed to climate change) would likely increase algae and invertebrates, increasing the prey base for some species.</p> <p>Vegetation management could adversely affect birds in the short term, but are expected to provide benefits in the long term. Wildlife disturbance could result from various actions, including uranium mining, the Grand Canyon Escalade Project, and recreational activities (hiking, rafting, fishing, and camping). Habitat loss is a concern for those projects involving the construction of roads, effluent ponds (mining), and buildings.</p>	<p>Most alternatives would have little effect on most wildlife species. Alternatives with more fluctuations, and less-even monthly release volumes (Alternatives A and B), would have greater impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic life stages. The proposed action’s contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.</p>

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Cultural resources	Cultural sites within Glen and Grand Canyons	Cultural resources are in an ongoing state of deterioration and natural erosive processes continue to destabilize these sites. Visitor traffic to GCNP exacerbates deterioration as artifacts exposed by erosion are moved or removed from the site. These effects are offset by enforcement of NPS's Backcountry Management Plan. It is not clear whether erosive processes will increase (with intense precipitation events) or decrease (with decreased precipitation) in the project area as a result of climate change. Ongoing dam operations may affect sediment availability, resulting in wind transport effects on GCNP cultural sites and reservoir shoreline cultural sites.	Alternatives with extended-duration HFEs (Alternatives D and G) could adversely impact terraces that support cultural resources in Glen Canyon. Alternatives with more HFEs (e.g., Alternatives C, D, E, F, and G) could provide for greater protection of sites by providing more sand for wind transport to these sites. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Tribal resources	Glen, Marble, and Grand Canyons	<p>Many Tribes regard the canyons as sacred space, the home of their ancestors, the residence of the spirits of their dead, and the source of many culturally important resources. Development related to projects like the Lake Powell Pipeline and uranium mining in the region, as well as fish/vegetation management practices, have ongoing adverse impacts on Tribe members. Actions and basin-wide trends affecting aquatic life, vegetation, and wildlife (as described above) would also affect resources of value to Tribes.</p> <p>Continued use of the riparian zone by visitors has the potential to damage places of cultural importance to the Tribes.</p>	All alternatives except Alternative F include either mechanical removal of trout or TMFs and may have an adverse impact to Tribes. Therefore, every alternative but Alternative F would contribute to cumulative impacts.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Recreation, visitor use and experience	Colorado River and associated recreational sites between Glen Canyon Dam and Lake Mead	<p>The HFE protocol has had a beneficial effect on camping and beach access (and therefore visitor use and experience) because it has a direct effect on sediment transport and deposition. Other actions taken by the NPS, as described in various management plans (tamarisk management, GCNP backcountry, noise and special flight rules, fire), also benefit visitor use and experience. The CRMP (which regulates boating and rafting) and the Comprehensive Fisheries Management Plan and Non-Native Fish Control Program are protective of natural/cultural resources and also have long-term beneficial effects on recreation and visitor experience.</p> <p>Warming water temperatures (and reduced flows below Glen Canyon dam) attributed to climate change could affect the health of the trout fishery below the dam, thus contributing to adverse cumulative impacts on recreation.</p>	<p>Most alternatives would result in a reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G). The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.</p>
Wilderness	Colorado River and associated recreational and wilderness sites between Glen Canyon Dam and Lake Mead	<p>The HFE protocol and other actions taken by the NPS, as described in various management plans (the CRMP, tamarisk management, GCNP backcountry, noise and special flight rules, fire) would benefit wilderness values and experience (although noise and visual effects associated with some actions diminish these values over the short term). The Grand Canyon Escalade would contribute to adverse impacts on visitors seeking solitude or a wilderness experience due to its visual and noise effects and the presence of infrastructure, all of which are incompatible with the character of GCNP.</p> <p>Basin-wide effects related to climate change (e.g., reduced water availability) could diminish wilderness values and experience by reducing opportunities for solitude.</p>	<p>Disturbance from non-flow actions would occur under all alternatives; the most crowding at rapids would occur under Alternative E; alternatives with greater fluctuations (e.g., Alternatives A, B, and E) could affect wilderness character. The program's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions</p>

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Visual resources	Shorelines and waters of the Colorado River between Glen Canyon Dam and Lake Mead; shorelines of lakes Powell and Mead; and the general landscape in the project area	Projected future declines in lake levels due to increased water demand, decreased water supply, the planned Lake Powell Pipeline project, and drought attributed to climate change could increase the likelihood of exposure of calcium carbonate rings and sediment deltas in lakes Powell and Mead. Infrastructure associated with the Lake Powell Pipeline project (pipeline, facilities, viewing platforms, and transmission lines), uranium mining, vegetation changes, and elements of the Grand Canyon Escalade development would also add to visual contrast and noticeable changes in the existing landscape.	LTEMP alternatives do not vary with respect to their impacts on visual resources. the proposed action’s contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions
Hydropower	Utilities and their customers who purchase power generated by Glen Canyon Dam Western Area Power Administration, Upper Colorado Basin Fund, environmental programs funded by CRSP power revenues; Upper Basin State apportionment-funded projects	<p>Increased demand for electricity in the service territories of the eight largest Western customer utilities and planned retirement of existing powerplant generating capacity would require an estimated 4,820 MW of new capacity to be built over the next 20 years.</p> <p>Changes in operations at Glen Canyon Dam since construction of the facility have resulted in reductions in generating capacity. Changes in operations under LTEMP alternatives could reduce available generating capacity further, necessitating the purchase of lost capacity from other sources and increasing the wholesale power rates to entities allocated preference power. This would consequently increase customer utility capacity costs and residential utility bills over time.</p>	Alternatives with higher fluctuation levels (Alternatives A, B, D, and E) achieve higher generation value and capacity, especially if more water is released in the high-demand months of July and August. However, the proposed action’s contribution to cumulative impacts would be small compared to the effects of past, present, and reasonably foreseeable future actions.

4-404

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Socioeconomics and environmental justice	Six-county region in the vicinity of the Colorado River between lakes Powell and Mead; recreational resources, including Lake Powell, Lake Mead, and the Grand Canyon (Colorado River)	<p>Projected future changes in lake levels and river flow due to increased water demand, decreased water supply, and drought attributed to climate change could be the greatest contributors to adverse impacts on the recreational use values associated with fishing, day rafting, and whitewater boating. The Grand Canyon Escalade would likely increase recreational visitation and expenditure rates along the Colorado River.</p> <p>The annual release volume from Glen Canyon Dam, as determined by the 2007 Interim Guidelines, also affects recreation economics.</p> <p>NPS regulates the number of boating trips (specified in the CRMP and the Comprehensive Fisheries Management Plan). Therefore, regional economics of these activities are not expected to change in the foreseeable future.</p>	<p>LTEMP alternatives result in relatively minor changes in use value and economic activity associated with lake and river recreation, and in residential retail rates. Environmental justice issues are associated with alternatives that incorporate frequent trout control actions (Alternatives C, D, and G), or result in increased economic impacts on Tribes associated with the cost of electricity (Alternatives F and G). The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions</p>

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Air quality and climate change	GCNP and the 11-state Western Interconnection region	<p>The construction of new (and the renewal of existing) fossil fuel-fired powerplants to meet increased energy demands from population and industrial growth in the region, coupled with drought conditions brought on by climate change (which increase the potential for wildfires and dust storms), could increase visibility degradation in the foreseeable future. The natural scattering of light would continue to be the main contributor to visibility degradation (haze) in the region, including GCNP. Other significant contributors would include wildfires, controlled burns, windblown dust, and emissions from metropolitan areas (manufacturing, coal-fired powerplants, and combustion sources like diesel engines).</p> <p>Hydropower generation at Glen Canyon Dam does not generate air emissions; however, dam operations can affect ambient air quality by causing a loss of generation that is offset by generation from coal, natural gas, or oil units. Under baseline operations (Alternative A), emissions of SO₂ and NO_x generated by powerplants affected by Glen Canyon Dam operations would be about 9.9% and 3.0% of the total emissions over the Western Interconnection region, respectively. Air quality impacts due to emissions under the other alternatives would be negligible because they would be only slightly increased or decreased relative to the baseline. Increases in GHG emissions associated with changes in operations under LTEMP alternatives would be negligible.</p> <p>The EPA’s Clean Power Plan Proposed Rule would have a beneficial impact on the air quality in the region by mandating reductions in CO₂ emissions from fossil fuel-fired powerplants. The closure of three coal-burning units at the FCPP would reduce levels of NO_x and PM pollutants that contribute to regional haze and visibility issues in the GCNP.</p>	LTEMP alternatives are expected to have negligible differences with respect to their impacts on air emissions including GHGs. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

1 The physical presence and design constraints of Glen Canyon Dam have created a new
2 baseline condition for resources within the Colorado River corridor, from Lake Powell and the
3 dam downstream and west to Lake Mead. Current safety and design requirements limit flow
4 through the dam to no more than 45,000 cfs, about 53% of its historical maximum flow.
5 Management of water flow within the river system is also constrained by the various treaties,
6 decrees, statutes, regulations, contracts, and agreements that are collectively known as the Law
7 of the River. Recent drought conditions in the Colorado River Basin have necessitated further
8 regulation (i.e., the 2007 Interim Guidelines) to reduce apportionments to the Lower Basin states
9 during periods of declining reservoir storage. The water supply and demand equation is further
10 stressed by the challenges of increasing demand in the seven Basin States (due to a rising
11 population) and the temperature variability and drought attributed to climate change, which are
12 projected to reduce flows into the foreseeable future.

13
14 As described in resource-specific sections in this chapter, the LTEMP alternatives are
15 expected to differ in the types and magnitude of impacts on specific resources. Against the
16 backdrop of past, present, and reasonably foreseeable future actions, however, the incremental
17 effects of the LTEMP alternatives, as described in the following sections, are expected to be
18 relatively minor contributions to cumulative impacts along the Colorado River corridor or within
19 the basin at large.

20 21 22 **4.17.3.1 Water Resources**

23
24 Although LTEMP alternatives differ in monthly, daily, and hourly flows all alternatives
25 comply with the 2007 Interim Guidelines. As a consequence, the impacts of alternatives do not
26 vary in their contribution to cumulative impacts on water supply and delivery.

27
28 Current water quality conditions and characteristics of Lake Powell (Section 3.2.2.1),
29 Colorado River below Glen Canyon Dam (Section 3.2.2.2), and Lake Mead (Section 3.2.2.3)
30 reflect the effects of past and present (ongoing) actions. Before Glen Canyon Dam was
31 constructed, the river was characterized by wide natural fluctuations in water quality
32 characteristics (e.g., temperature, salinity, turbidity, and nutrients). In the post-dam era, these
33 variations are moderated and the river has seen an overall improvement in water quality. Future
34 water quality would likely be affected most by increased water demand and climate change.
35 Although most alternatives would likely result in a slightly increased potential for bacteria and
36 pathogens along shorelines, the contribution of continued operations under the LTEMP to
37 cumulative impacts on water quality is expected to be negligible regardless of which alternative
38 is selected.

39
40 As the population in the Basin States grows and expands, municipal, industrial, and
41 agricultural water demand continues to increase. In its 2013 study, Reclamation concluded that
42 the total consumptive use and loss (i.e., surface water and groundwater depletions and
43 evaporative losses) for the Arizona portion of the Upper Colorado River Basin (covering about
44 6,900 mi²) was 35,037 ac-ft, more than half of which is water pumped directly from Lake Powell
45 and used by the Navajo Generating Station (Reclamation 2014e).

1 Urban runoff, industrial releases, and municipal discharges are considered some of the
2 leading nonpoint sources of contaminants to surface waters (EPA 2004). Areas of intensive
3 agriculture can have an adverse effect on the water quality as a result of the salinity, nutrients,
4 pesticides, selenium, and other trace elements that are common constituents in agricultural
5 runoff. As a result, water management and efficient water use (as is the goal of the 2007 Interim
6 Guidelines) become important variables in the Colorado River supply and demand equation
7 (Beckwith 2011). The interim guidelines have improved water supply conditions through
8 increased water conservation efforts, which in turn are providing more predictability in water
9 supply to users in the Basin States (especially the Lower Basin).

10
11 The general picture for climate change, as it relates to Colorado River Basin hydrology,
12 includes decreased inflow to the reservoir system (e.g., lower precipitation) and greater losses
13 (e.g., evapotranspiration associated with higher temperatures and increased demand from the
14 growing population). Climate change is expected to result in more frequent and severe drought
15 conditions in the Southwest. Meeting increasing water needs (e.g., the Lake Powell Pipeline
16 project and the Page-LeChee water supply project) will likely lead to lower reservoir levels in
17 Lake Powell, which may already be affected by increased evaporation associated with higher air
18 temperatures. As discussed in Section 4.2.2, decreasing the elevation of Lake Powell can lead to
19 warmer water discharges from Glen Canyon Dam and increased water temperatures downstream.

20 21 22 **4.17.3.2 Sediment Resources**

23
24 The construction and presence of Glen Canyon Dam has affected Glen, Marble and
25 Grand Canyons by (1) reducing the sediment supply, and by (2) reducing the annual peak flows.
26 Among the actions considered under LTEMP, HFE releases (which are highest under
27 Alternatives C, D, E, F, and G) have the greatest impact on sediment resources (and sandbar
28 building potential), although variability in hydrology or sediment supply from tributary inputs
29 has a greater impact than HFEs. Cumulative impacts that affect this variability in hydrology and
30 sediment supply (such as climate change) have the potential to affect sediment resources in the
31 future.

32
33 It has been estimated that the post-dam sand supply to Marble Canyon is less than 10% of
34 the pre-dam supply (Topping et al. 2000a; Topping, Rubin, Nelson et al. 2000; Wright,
35 Schmide et al. 2008), with the majority of the sediment evacuation between the dam and
36 Phantom Ranch (RM 87) occurring during the three decades following dam construction. The
37 reduced sediment supply would move downstream at different rates in the various LTEMP
38 alternatives, but sediment supply to Marble and Grand Canyons would not differ among the
39 alternatives. The 1996 ROD modifications to the flow regime resulted in benefits for the building
40 and retention of sandbars

41
42 Future climate change implications on sediment resources are highly variable and cannot
43 be accurately quantified. Conceptually, climate change can affect the sediment resource in two
44 ways: by changing the hydrology in the drainage area upstream of Glen Canyon Dam, and by
45 changing the hydrology in the drainage area downstream of Glen Canyon Dam, especially in the
46 drainage area of primary sediment contributors such as the Paria River and the Little Colorado

1 River. A drier future hydrology in these drainage areas could decrease the availability of sand in
2 Marble and Grand Canyons.

3 4 5 **4.17.3.3 Natural Processes**

6
7 Cumulative impacts on natural processes (water flow, water temperature, and sediment
8 supply) reflect those discussed under water resources (Section 4.17.3.1) and sediment resources
9 (Section 4.17.3.2). Although some of the LTEMP alternatives could affect these resources
10 (e.g., potential sandbar growth through implementation of HFE releases, which is greatest under
11 Alternatives C, D, E, F, and G), the incremental effects of the alternatives are not anticipated to
12 contribute significantly to cumulative impacts on natural processes along the Colorado River
13 corridor or within the basin at large. Implementation of HFEs could result in an improvement in
14 sandbar building over the long term. Climate change (and its effects on water flow, water
15 temperature, and sediment supply), however, would likely have a greater effect on natural
16 processes than any of the LTEMP alternatives.

17 18 19 **4.17.3.4 Aquatic Ecology**

20
21 Section 3.5.1 describes the current conditions of the aquatic food base in the Colorado
22 River downstream of Glen Canyon Dam. The current state of the aquatic food base reflects the
23 effects of past and present (ongoing) actions; Section 4.5.3 discusses potential impacts of the
24 various LTEMP alternatives. The aquatic food base may also be affected by other reasonably
25 foreseeable actions, particularly climate change, dam modification, water use, introduction of
26 nonnative species, and uranium mining.

27
28 Population growth, industrial development, and the warming associated with climate
29 change will act in concert to increase demand for water (Schindler 2001). Climate change is also
30 expected to result in more frequent and severe drought conditions in the Southwest, which will
31 continue to tax water supplies. Combined with increased evaporation associated with higher
32 temperatures, meeting water needs would lead to lower reservoir levels in Lake Powell. The
33 Lake Powell Pipeline Project would also contribute to lower Lake Powell reservoir elevations
34 (FWS 2011c). Lowering of Lake Powell elevations can lead to warmer water discharges from
35 Glen Canyon Dam. The Red Gap Ranch Pipeline, which would withdraw groundwater
36 contributing to the base flow of the Little Colorado River, could reduce habitat availability and
37 suitability in the Little Colorado River with subsequent adverse effects on humpback chub and
38 designated critical habitat, although the magnitude of these impacts have not been quantified.

39
40 Warmer water temperatures would likely increase production rates of algae and
41 invertebrates (Woodward et al. 2010; FWS 2011c). Lower levels of Lake Powell may also result
42 in increases in the composition and density of zooplankton downstream of Glen Canyon Dam,
43 because waters would be withdrawn closer to the surface (Reclamation 1995). However, warmer
44 temperatures, particularly in winter, may allow many invertebrate species to complete their life
45 cycles more quickly (Schindler 2001). For example, if stream temperatures are raised by only a
46 few degrees in winter, many aquatic insects that normally emerge in May or June may emerge in

1 February or March and face death by freezing or be prevented from mating because of being
2 inactivated by low air temperatures. In addition, increases in stream temperatures may cause an
3 exaggeration in the separation of the emergence of males and females (e.g., males may emerge
4 and die before females emerge) (Nebeker 1971). Temperatures above the optimum can lead to
5 the production of small adults and lower fecundity (Vannote and Sweeney 1980).
6

7 Warmer water temperatures can expand the distribution of nonnative species adapted to
8 warmer temperatures. This includes fish parasites such as the Asian tapeworm, anchor worm,
9 and nonnative crayfish. Increased zooplankton due to climate change may increase abundance of
10 cyclopoid copepods. All cyclopoid copepod species appear to be susceptible to infection by, and
11 therefore serve as intermediate hosts for, the Asian tapeworm (Marcogliese and Esch 1989).
12 Crayfish can prey on fish eggs and larvae and can diminish the abundance and structure of
13 aquatic vegetation such as filamentous algae through grazing (FWS 2011c). Nonnative crayfish
14 are present in Lake Powell (northern or virile crayfish [*Orconectes virilis*]) and Lake Mead (red
15 swamp crayfish [*Procambarus clarkii*]). Warmer temperatures may allow the crayfish to expand
16 into the mainstem of the Colorado River either downstream of Lake Powell or upstream of Lake
17 Mead.
18

19 As discussed in Section 3.5.1, some nonnative species introductions occurred in order to
20 supplement the aquatic food base (e.g., *Gammarus*, snails, and midges); while accidental
21 introductions have occurred via fish stocking and recreational fishing, often with detrimental
22 effects on both lower trophic levels or fish species (e.g., the New Zealand mud snail and parasitic
23 trout nematode [*Truttaedacnitis truttae*]). The quagga mussel (*Dreissena bugensis*), which is
24 established in Lake Powell, may develop viable populations in the mainstem of the Colorado
25 River, at least within the Glen Canyon reach.
26

27 Concern has been raised about the diatom *Didymosphenia geminata* (“didymo”) becoming established in the Colorado River. High-density blooms of didymo are frequent in
28 rivers directly below impoundments. In these river reaches, stable flows and fairly constant
29 temperatures favor development of large masses of didymo (see Spaulding and Elwell 2007).
30 Didymo can form nuisance benthic growths that extend for more than 1 km and persist for
31 several months (Spaulding and Elwell 2007). Mayflies, stoneflies, caddisflies, and dragonflies
32 have an inverse relationship with didymo coverage, while midges and aquatic worms dominate
33 didymo-covered areas (Larson and Carreiro 2008). Nevertheless, the presence of didymo has
34 been associated with increased periphyton biomass and increased invertebrate densities and
35 richness (Kilroy et al. 2009; Gillis and Chalifour 2010). Given the large amounts of non-
36 nutritious stalk material present on stream substrates in affected areas, didymo is predicted to
37 have deleterious effects on native fish, especially those that inhabit benthic habitats, consume
38 benthic prey, and nest beneath or between cobbles (see Spaulding and Elwell 2007). Didymo is
39 present in waters from 4 to 27°C (39 to 81°F) (Spaulding and Elwell 2007), so warming would
40 not be a factor in its occurrence in the Colorado River. However, development of didymo blooms
41 likely requires both low mean discharge and variation in discharge. Scouring events usually
42 remove didymo stalk material from substrates (Kirkwood et al. 2007).
43
44

45 Uranium mining peaked in the 1980s in the Grand Canyon region, but there is now a
46 renewed interest due to increases in uranium prices. Increased uranium mining (on state and

1 private lands) could increase the amount of uranium, arsenic, and other trace elements in local
2 surface water and groundwater flowing into the Colorado River (Alpine 2010). Uranium, other
3 radionuclides, and metals associated with uranium mines can affect the survival, growth, and
4 reproduction of aquatic biota.

5
6 Aquatic biota and habitats most likely to be affected during mine development and
7 operation are those associated with small, ephemeral, or intermittent drainages. Impacts on
8 aquatic biota and habitats from the accidental release of regulated or hazardous materials into
9 ephemeral drainages would be localized and small, especially if a rapid response to a release is
10 undertaken. The accidental spill of uranium ore into a permanent stream or river such as Kanab
11 Creek would potentially pose a localized short-term impact on the aquatic resources. However,
12 the potential for such an event is extremely low. Most ore solids would settle in the waterbody
13 within a short distance from a spill site (Edge Environmental, Inc. 2009). It is expected that
14 expedient and comprehensive cleanup actions would be required under U.S. Department of
15 Transportation regulations and that an emergency response plan would be in place for
16 responding to accidents and cargo spills (Edge Environmental, Inc. 2009). Overall, the potential
17 for impacts on aquatic biota from an accidental spill would be small to negligible. Spencer and
18 Wenrich (2011) estimated that if an ore load is washed into the Colorado River and is pulverized
19 and dissolved (a scenario that is extremely unlikely to impossible), the uranium concentration in
20 the river would increase from the current 4.0 ppb to only 4.02 ppb (undetectable against natural
21 variations). Predicted no chemical effect concentrations for aquatic vascular plants, aquatic
22 invertebrates, and fish are ≥ 5.0 ppb; the lowest chronic concentrations are well above that
23 concentration (see Hinck et al. 2010). For these reasons, the impacts from uranium mining on
24 aquatic biota in the Colorado River or its major tributaries would be localized and would not
25 reduce the viability of affected resources.

26
27 The incremental effects of the LTEMP alternatives on fish are not expected to contribute
28 significantly to cumulative impacts along the Colorado River corridor or within the basin at
29 large. Examination of the various hydrologic traces used to model effects of alternatives on
30 aquatic resources indicated that hydrology (i.e., whether a 20-year trace was drier or wetter on
31 average) had a greater influence on the model results than the operational differences among
32 alternatives. Similarly, climate change has the potential to have greater effects on fish resources
33 than any of the alternatives because of its direct influences on hydrologic patterns. For example,
34 more frequent droughts and warmer atmospheric temperatures have the potential to result in
35 greater increases in the temperature of water being released from the dam than the operational
36 actions being considered, and this in turn may improve thermal suitability for humpback chub,
37 humpback chub aggregations, and native fish. However, any subsequent benefits may be offset
38 by increased abundance and expansion of nonnative fish and aquatic fish parasites. There are a
39 number of other actions being taken within the Colorado River Basin that could also contribute
40 to significant cumulative effects on fish populations or fish communities. For example, actions to
41 increase the number of self-sustaining populations of humpback chub within the basin
42 (e.g., translocation of humpback chub from the Little Colorado River to other tributaries within
43 the Grand Canyon) have the potential to increase overall numbers of humpback chub and could
44 provide some level of protection against catastrophic events in the Little Colorado River that
45 could greatly reduce or eliminate the population of humpback chub in the Grand Canyon.

1 **4.17.3.5 Vegetation**
2

3 In addition to effects of releases from Glen Canyon Dam and NPS’s experimental
4 vegetation restoration program, factors that would impact riparian plant communities include the
5 tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil (*Coniatus* spp.), which occur
6 along much of the Colorado River below Glen Canyon Dam. By late 2012, the tamarisk leaf
7 beetle had been found in many locations in the Grand Canyon, with an estimated 70% defoliation
8 at some sites (Johnson et al. 2012). Tamarisk leaf beetle is not expected to have impacts on
9 populations of other plant species, such as native shrubs (Dudley and Kazmer 2005). Fire
10 management policies for GCNP include fuel reduction by removal of dead woody material as
11 well as fire suppression; however, riparian areas are generally avoided (NPS 2012d).
12

13 The replacement of tamarisk by other species and the timing of replacement would be
14 affected by flow characteristics as well as site-specific factors. The potential reduction in the
15 dominance of tamarisk in many areas and the decrease in total area of tamarisk-dominated
16 communities along the Colorado River could result in an increase in native species or, more
17 likely, other nonnative species, especially where soils have high nitrogen levels
18 (Hultine et al. 2010; Shafroth et al. 2005, Shafroth, Brown et al. 2010; Belote et al. 2010;
19 Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012; Bateman et al. 2013).
20 Many nonnative species are already present along portions of the Colorado River and Lake Mead
21 (Table 4.6-5). Short-term changes in nutrient dynamics in the riparian ecosystem could also
22 occur with increased activity of tamarisk leaf beetles, with subsequent effects on the future
23 development of native or nonnative communities (Uselman et al. 2011). Soil seed banks may
24 contain a high diversity of species and would potentially influence subsequent plant community
25 composition; however, the regrowth of native species may be slow (Reynolds and Cooper 2011;
26 Belote et al. 2010).
27

28 As discussed in Section 4.6, hydrologic conditions have a greater effect on native
29 community types in the Fluctuation Zone and New High Water Zone than do the operational
30 characteristics of the LTEMP alternatives. Within each alternative, the occurrence of flows with
31 significant effects on riparian vegetation, such as extended high flows and extended low flows,
32 are determined in large part by the inflow to Lake Powell as a result of hydrologic variation
33 (Section and 4.2). Other events, such as spill flows (flows >45,000 cfs that would necessitate use
34 of the spillway) could have pronounced effects on riparian vegetation, but these too result from
35 hydrologic variation and not characteristics of the alternatives. However, with forecasting
36 capabilities currently used by the Bureau of Reclamation, it is unlikely that spill flows would
37 occur in the future. Within a year, under any alternative, monthly operations may be increased or
38 decreased based on changing annual runoff forecasts, and application of the Interim Guidelines
39 for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead
40 (Reclamation 2007a).
41

42 Feral burros contribute to cumulative impacts on riparian vegetation, especially
43 vegetation in the Old High Water Zone. Researchers documented vegetation impacts from feral
44 burros as early as 1974, noting vegetation destruction and decreases in species diversity. These
45 impacts, along with impacts on soils, remain visible on the landscape today with very little
46 vegetation recovery (Leslie 2004).

1 Visitation from commercial and private river trips, as well as backcountry hikers and
2 anglers, also can affect vegetation. Visitors have created trails and added to the loss of vegetation
3 in upland and Old High Water Zone areas. Administrative actions such as tamarisk eradication
4 projects and archaeological site monitoring programs can also contribute to vegetation impacts.
5 The intentional or unintentional spread of exotic plant species by humans coming into the area of
6 effect contributes to the current levels of impacts along the Colorado River corridor. This can
7 have localized, adverse, short- or long-term, year-round effects on vegetation by visitors in the
8 riparian zone, and has effects in camping areas, trails, and in popular visitation areas
9 (NPS 2006b).

10
11 Riparian ecosystems are expected to be affected by long-term changes in the climate
12 across the Colorado River watershed. Under a climatic trend of lower precipitation, there would
13 likely be fewer years with extended high flows and an increase in the number of years with
14 extended low flows under any of the alternatives. It is also possible that, with lower regional
15 precipitation, there could be fewer sediment-triggered HFEs if the Paria River delivers less
16 sediment. Riparian plants in the Old High Water Zone are expected to continue to decline. The
17 New High Water Zone would tend to experience a shift toward more drought-tolerant species,
18 such as arrowweed and mesquite. Tamarisk is tolerant of drought stress, and has an advantage
19 over native species that require access to groundwater, such as cottonwood and willow, in areas
20 where water tables are lowered. Thus, tamarisk may be maintained under drier climate
21 conditions, although recruitment events may be limited and, as noted above, effects of
22 defoliation may greatly affect tamarisk-dominated communities. Communities that require a
23 shallow water table or relatively frequent inundation, such as marsh, shrub wetland, and
24 cottonwood-willow woodland, would likely decline.

25
26 Natural events, such as floods inside canyons and rockfalls, scour vegetation; this can add
27 to the loss of diverse and intact native vegetation and contribute to the spread of invasive, exotic
28 plant species. In addition, as noted in Section 3.6.2, years with unusually high inflow into Lake
29 Powell, such as 1983, may result in emergency dam releases greater than 45,000 cfs that would
30 have major and lasting effects on vegetation (Mortenson et al. 2011; Ralston 2012).

31
32 The effects of the LTEMP alternatives on riparian vegetation communities are relatively
33 small compared to the effects of other factors, especially future hydrology. For this reason, the
34 incremental effects of the alternatives on native and nonnative plant species are not expected to
35 contribute significantly to cumulative impacts along the Colorado River corridor or within the
36 basin at large. Most alternatives, including Alternative A, are expected to result in a decrease in
37 native community cover and wetlands. Alternative D is the only alternative that is expected to
38 result in an overall improvement in vegetation.

39 40 41 **4.17.3.6 Wildlife**

42
43 Section 3.7 describes the current condition of wildlife in the Grand Canyon, which
44 reflects the effects of past and present cumulative impacts; Section 4.7 discusses the potential
45 impacts the various LTEMP alternatives may have on wildlife. Because the assessment of
46 impacts on wildlife is based partly on an evaluation of impacts on the aquatic food base, fish

1 (Section 4.5.2), and riparian vegetation (Section 4.6), cumulative impacts on those resources will
2 also result in cumulative impacts on wildlife. Wildlife may also be affected by other reasonably
3 foreseeable future actions and basin-wide trends contributing to cumulative impacts
4 (Sections 4.17.1.2 and 4.17.2), particularly water use, climate change, vegetation management,
5 AML closure, fire, trout management, introduction or spread of nonnative species, human-
6 associated noise and visual disturbance (e.g., from recreation), and uranium mining.

7
8 Population and industrial growth, coupled with climate change, will act in concert to
9 increase water demand in the region (Schindler 2001) and lower flows downstream of Glen
10 Canyon Dam. This could stress existing riparian and wetland vegetation, leading to plant
11 community alterations that would affect both wildlife habitats and the wildlife prey base. Climate
12 change would not affect all wildlife species uniformly. Some species would experience
13 distribution contractions and likely shrinking populations while other species would increase in
14 suitable areas and thus possibly experience increases in population numbers. Generally, the
15 warmer the current range is for a species, the greater the projected distributional increase (or
16 lower the projected loss) will be for that species due to climate change (van Riper et al. 2014).

17
18 Lowering of Lake Powell elevations can lead to warmer water discharges from Glen
19 Canyon Dam. Warmer water temperatures would likely increase production rates of algae and
20 invertebrates (Woodward et al. 2010; also see FWS 2011c) leading to increases in the prey base
21 for some wildlife species such as amphibians, lizards, waterfowl, insectivorous songbirds, and
22 bats.

23
24 Riparian vegetation management activities (e.g., removal of nonnative plants and native
25 plant restoration) would modify the cover, stratification, and distribution of plant communities
26 along the Colorado River. Eradication of tamarisk could affect birds by altering prey availability,
27 increasing nest abandonment and predation, and reducing the quantity of riparian habitat
28 available to breeding birds (Paxton et al. 2011). In the long term, riparian vegetation
29 management may diversify riparian habitats and establish a more productive wildlife community.
30 Additional factors that could affect riparian wildlife habitat include the tamarisk leaf beetle and
31 splendid tamarisk weevil, which occur along much of the Colorado River below Glen Canyon
32 Dam and result in defoliation and mortality of tamarisk (Section 4.17.3.4). Widespread tamarisk
33 mortality would likely result in a net loss in riparian habitat for at least a decade or more
34 (Paxton et al. 2011). It seems unlikely that the effects of large-scale defoliation in areas
35 dominated by tamarisk will be compensated for by use of tamarisk beetles as a food resource by
36 birds (Puckett and van Riper 2014).

37
38 The highly flammable tamarisk has created a fire hazard previously absent along the
39 river. This threatens breeding bird populations, as well as other wildlife. In addition, if native or
40 mixed habitat stands burn, monotypic tamarisk will likely recolonize, eliminating the crucial
41 structure necessary for southwestern willow flycatchers and other nesting birds (e.g., thermal
42 buffering through shading becomes insufficient and will be further exacerbated by warming
43 climate trends) (Schell 2005).

44
45 The quagga mussel (*Dreissena rostriformis bugensis*), which is currently established in
46 Lake Powell, may develop viable populations in the mainstem of the Colorado River, at least

1 within the Glen Canyon reach. An established population of quagga mussels may increase the
2 prey base available to diving ducks. Warmer temperatures may allow crayfish inhabiting Lake
3 Mead and Lake Powell to expand into the mainstem of the Colorado River, providing an
4 additional prey item for some wildlife species.

5
6 In the past, uranium mining led to localized peregrine falcon nest failures in areas such as
7 Kanab Canyon and its multiple side canyons, where numerous mining claims existed
8 (Payne et al. 2010). Although 684,449 ac of federal land administered by BLM north of GCNP
9 (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of
10 GCNP (South Parcel) would be withdrawn from locatable mineral exploration and development
11 (i.e., uranium mining), increased uranium mining on non-federal (state and private) lands
12 remaining open to mining could locally affect wildlife habitat (e.g., habitat loss and
13 fragmentation) and increase the amount of uranium, arsenic, and other trace elements in local
14 surface water and groundwater flowing into the Colorado River (Alpine 2010). Edge habitat
15 associated with uranium mines and associated access roads may provide habitat for brown-
16 headed cowbirds (Payne et al. 2010), which are brood parasites of songbirds. Grazing and
17 recreation, including use of commercial pack-stock, also increase brown-headed cowbird
18 populations (Schell 2005). Habitat loss from uranium mines and associated access roads could
19 affect the distribution and movement of big game mammals (e.g., elk, mule deer, bighorn sheep,
20 and mountain lions), and potentially increase their mortality from vehicle collisions or poaching
21 (Payne et al. 2010). There could be a potential contaminant exposure issue associated with
22 amphibians (or other wildlife) attracted to uranium mine effluent ponds (Payne et al. 2010). In
23 general, any impacts on wildlife from uranium mining would be localized and should not affect
24 the viability of affected resources, especially with the use of best management practices to
25 control mine discharges and proper mine reclamation.

26
27 The Grand Canyon Escalade Project and its associated facilities near the confluence of
28 the Little Colorado River could cause both a localized loss of wildlife habitat and source of
29 wildlife disturbance due to human presence. Wildlife species in the Grand Canyon are currently
30 exposed to various sources of manmade noise ranging from human conversation to aircraft
31 flyovers. The potential effects of noise on wildlife include acute or chronic physiological damage
32 to the auditory system, increased energy expenditures, physical injury incurred during panicked
33 responses, interference with normal activities (e.g., feeding), and impaired communication
34 (AMEC Americas Limited 2005). The response of wildlife to noise would vary by species;
35 physiological or reproductive condition; distance; and the type, intensity, and duration of the
36 disturbance. Regular or periodic noise could cause adjacent areas to be less attractive to wildlife
37 and result in a long-term reduction in use by wildlife in those areas. Responses of wildlife to
38 disturbance often involve activities that are energetically costly (e.g., flying or running), altering
39 their behavior in a way that might reduce food intake, communication, and nesting
40 (Hockin et al. 1992; Brattstrom and Bondello 1983; Cunningham and Fahrig 2010;
41 Francis et al. 2009; Maxell 2000).

42
43 Recreational activities such as hiking, rafting, fishing, and camping can result in
44 disturbance to wildlife. For example, hikers, rafters, anglers, and researchers can disturb bald
45 eagles; however, southwestern willow flycatchers are not apparently sensitive to rafts or boats
46 passing their breeding sites, but people moving through occupied habitat can disturb the birds or

1 impact a nest (Holmes et al. 2005). Impacts on reptiles and amphibians can include occasional
2 opportunistic collecting or harassment by recreationists. As demand for reptiles in the pet trade
3 increases and collectors seek new sources of supply, many national parks are experiencing
4 problems with illegal reptile collection, especially of rattlesnakes (NPS 2014h). Recreationists
5 can affect birds and other wildlife by removing or modifying vegetation within both the new and
6 old high-water zones (e.g., for campsites and trails) (NPS 2005a).

7
8 During winter 1990–1991, more eagles were detected in reaches with low human use
9 compared to reaches with high to moderate human use between Glen Canyon Dam and the Little
10 Colorado River. No eagles were found within 1 km of intensively used areas near Lees Ferry and
11 Navajo Bridge. Repeated flushing by bank fishermen, hikers, or boats could have caused
12 wintering eagles to avoid reaches heavily used by anglers (Brown and Stevens 1997). Winter
13 camping, especially in important eagle activity areas, can disturb bald eagles and has the
14 potential to seriously disrupt a wintering eagle concentration (Sogge and Tibbitts 1994).

15
16 The effects of the LTEMP alternatives on wildlife are relatively small compared to the
17 effects of other factors, especially future hydrology, and are not expected to contribute
18 significantly to cumulative impacts along the Colorado River corridor or within the basin at
19 large. Most alternatives would have little effect on most wildlife species. Alternatives with more
20 fluctuations, and less even monthly release volumes (Alternatives A and B), would have greater
21 impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic
22 life stages.

23 24 25 **4.17.3.7 Cultural Resources**

26
27 The proposed action is not expected to significantly change the ongoing cumulative
28 impacts on historic properties. Past dam operations resulted in transformations to the
29 environment that may contribute to the nature, severity, and rate of erosive forces having the
30 potential to act upon and influence the integrity of these historic properties. The past action
31 primarily affecting these resources was the construction and operation of the Glen Canyon Dam
32 and the resulting loss of sediment in the river channel below the dam.

33
34 The river immediately downstream from Glen Canyon Dam was intentionally scoured in
35 1965 during a series of high-pulse flows. These pulse flows, coupled with other dam operation
36 activities, transformed the pre-dam Glen Canyon, which had plentiful sand, native species, and
37 active natural processes, to a present-day Glen Canyon that is incised, narrowed, and armored
38 (Grams et al. 2007). The Glen Canyon Dam has prevented sediment-laden extreme high flows
39 that occurred periodically in the past and allowed for both deposition and erosion at higher
40 elevations, as well as extreme low flows that exposed sandbars and allowed wind transport to
41 higher elevation terraces.

42
43 For GCNRA, these transformations include bed incision and reduction in the base level
44 of erosion, sediment evacuation and exposure of terrace faces, and changes in gully type and
45 formation processes. The degree to which these transformations may contribute to impacts on
46 historic properties remains poorly understood, and is the subject of ongoing research. For GRCA,

1 these transformations are primarily tied to loss of low-elevation sandbars and the degradation of
2 the pre-dam river terraces that were home to peoples for the past 10,000 years.

3
4 In addition, the effects from visitors remain a persistent issue, although not overarching.
5 The proposed action pertains to the operation of Glen Canyon Dam and does not alter any
6 policies concerning visitor use of the river. The concern over visitor effects is exacerbated by
7 erosion, which continues to expose additional portions of archaeological sites. The more artifacts
8 are exposed at a site, the more opportunities exist for a visitor to pick up an artifact and move it.
9 Only education can make visitors aware of the need to leave the artifacts as they lie.

10
11 Historic properties in the APE remain in a continual state of deterioration. The erosive
12 forces that created the Grand Canyon continue to operate throughout both GCNRA and GCNP
13 and continue to destabilize the historic properties found there. The degradation of historic
14 properties due to natural causes remains the biggest challenge faced by historic property
15 managers. Rain events cause gulying and remove the sediment that surrounds the historic
16 properties along the Colorado River. Little can be done to slow these climatic processes although
17 implementing management strategies to stabilize and minimize sediment losses may be effective
18 tools in the future.

21 **4.17.3.8 Tribal Resources**

22
23 Actions contributing to cumulative impacts on Tribal resources include the continued use
24 or reopening of breccia pipe uranium mines adjacent to the park, the development of new mines
25 on state land lying within the Grand Canyon watershed, continued traffic of visitors to sites
26 sacred to the Tribes, and specific projects, including the Lake Powell Pipeline, the Grand Canyon
27 Escalade, and the Red Gap Ranch Pipeline.

28
29 Uranium prospecting and mining in the Grand Canyon watershed could contribute to
30 cumulative effects on Tribes. Uranium mining has the potential to contaminate water sources that
31 supply aquifer systems that feed springs, seeps, and their associated ecosystems within Grand
32 Canyon National Park (GCNP 2013). Many Tribes consider drilling or mining to be wounding
33 the earth (BLM 2011). In 2012, the decision was made to withdraw over a million acres of
34 federal lands surrounding GCNP in northern Arizona from uranium mining for the next 20 years.
35 However, four existing mines were grandfathered and continue to operate intermittently as the
36 price of uranium fluctuates. In addition, the withdrawal of federal lands has resulted in the
37 concentration of new uranium exploration on state lands, some of which are within the Grand
38 Canyon watershed. Past mining has resulted in the contamination of springs and seeps feeding
39 the Grand Canyon, reducing their sacred nature. Uranium mining is currently taking place at
40 sacred sites, including the Red Butte Traditional Cultural Property south of GCNP. Tribes in the
41 region have expressed concern that contamination in the drainage to Havasu Canyon or in other
42 watersheds and aquifers would be devastating to the downstream resources of importance to the
43 Havasupai (Havasupai Tribal Council 2015). However, the LTEMP alternatives do not include
44 any action that would result in water contamination and none are expected to contribute to
45 cumulative impacts.

1 Continued use of the riparian zone by visitors to the canyons has the potential to result in
2 damage to places of cultural importance to the Tribes. Continued disturbance over time and
3 space could result in the loss of the function and sacredness of traditional cultural places. These
4 potential losses can be partially mitigated by the education of canyon visitors regarding the
5 sanctity of the canyons.
6

7 Actions affecting aquatic life, vegetation, and wildlife would also affect resources of
8 value to Tribes (see Sections 4.5, 4.6, and 4.7). For example, changes in the tamarisk population
9 due to the tamarisk leaf beetle and splendid tamarisk weevil, as well as long-term changes in the
10 climate could contribute to cumulative impacts on riparian ecosystems across the Colorado River
11 watershed. A summary of such impacts on Tribal resources is provided in Section 4.9.3.
12

13 The Lake Powell Pipeline proposes to carry water from Lake Powell to Sand Hollow
14 Reservoir near St. George, Utah, to help meet water demand in southwestern Utah
15 (UBWR 2011c). Impacts on historic properties have not been assessed for this project. Impacts
16 on other resources of Tribal importance from the pipeline could include loss of some wildlife
17 habitat and temporary loss of vegetation and riparian communities. The Red Gap Ranch Pipeline,
18 which would withdraw and convey groundwater to augment Flagstaff's water supply, could
19 affect springs of importance to Tribes, although the impacts of this action have not yet been
20 assessed.
21

22 LTEMP alternatives that include mechanical trout removal or TMFs (all Alternatives
23 except F), may have an adverse effect that would add to the cumulative impacts on Tribal
24 resources (see also Table 4.9-2).
25
26

27 **4.17.3.9 Recreation, Visitor Use, and Experience**

28
29 Section 3.10 presents the recreational resources and activities that could be affected by
30 the LTEMP alternatives. Most of the LTEMP alternatives would result in fewer navigation
31 concerns, lower catch rates, and increased camping area (with the greatest potential increase in
32 camping area under Alternative G and higher catch rates under Alternatives F and G).
33 Section 4.10 presents the estimated incremental effects of the alternatives on those recreational
34 resources and activities. The following paragraphs analyze the potential cumulative effects of
35 past, present, and future actions on recreation resources that may also incur incremental effects
36 from the LTEMP alternatives. Other resources analyzed separately that could incur cumulative
37 effects that might also affect recreation include sediment, water quality, and the trout fishery
38 below Glen Canyon Dam.
39

40 Some, but not all, of the past and present actions described in Section 4.17.1.1 could have
41 effects on recreation. Such past and present actions that could affect camping and beach access
42 are those that affect sediment transport and deposition. Among these, the 2007 Interim
43 Guidelines affect sediment retention and deposition through required equalization flows, which
44 tend to erode beaches, while the 2011 HFE protocol would benefit beach and campsite building
45 through sediment deposition. Such effects are already captured in the analysis of the LTEMP
46 alternatives, which are subject to the provisions of ongoing programs.

1 Among ongoing actions that could affect recreation, visitor use, and experience, is the
2 2006 CRMP, which sets the number of annual launches for commercial and noncommercial
3 boating and rafting.
4

5 The Comprehensive Fisheries Management Plan and the Non-native Fish Control
6 Program would protect and benefit recreational fishing below Glen Canyon Dam. These two
7 management programs would limit the effects of the LTEMP alternatives on the recreational
8 fishery. Most of the alternatives incorporate management actions consistent with these plans,
9 including TMFs and mechanical removal of trout. These plans and actions would tend to reduce
10 cumulative impacts on the trout fishery through active management.
11

12 Of the reasonably foreseeable future actions, the proposed Grand Canyon Escalade
13 project, including a gondola running from the canyon rim to the canyon floor near the confluence
14 of the Little Colorado River and the Colorado River would contribute to cumulative impacts on
15 recreational resources. The nature of effects, positive or negative, would depend on the
16 perspective of a particular visitor. Users of the facility would benefit from the services offered.
17 Adverse effects on wilderness experience are discussed in Section 4.17.10. Overall, however,
18 effects of the Escalade project on recreationists are expected to be negative, because the vast
19 majority of visitors come to experience natural beauty and solitude, which is incompatible with
20 development within the Grand Canyon.
21

22 Climate change could affect recreation resources in a number of ways, some of which
23 would add significantly to effects from ongoing actions and trends discussed. Warming
24 temperatures could reduce runoff and water supply to the Colorado River and increase water
25 demand from municipalities and for cooling, further reducing supply. Reduced availability of
26 water could lower the elevation of Lake Powell, leading to warming and reduced flows below the
27 Glen Canyon Dam. Warming could reduce DO levels in tailwaters. These factors could affect the
28 health of the trout fishery below the dam and could affect boating through lower flows and
29 higher daily fluctuations, as discussed in the previous paragraph. The combination of climate
30 change and increasing water demands from regional population growth could increase the
31 cumulative effects of reduced water availability.
32

33 The LTEMP alternatives would vary with respect to recreation, but would not
34 significantly add to cumulative effects on recreation. Most alternatives would result in a
35 reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and
36 increased camping area (with the greatest potential increase in camping area under Alternative G
37 and higher catch rates under Alternatives F and G).
38

39 40 **4.17.3.10 Wilderness**

41
42 Wilderness character, as used in this DEIS, is defined in Section 3.11, as are the
43 wilderness values and experience that may be impacted by LTEMP alternatives. Section 4.11
44 analyzes potential direct impacts on wilderness values and experience of the alternatives. In this
45 section, potential cumulative effects on wilderness experience caused by other past, present, or

1 future actions in the region are analyzed; aspects of the analysis of cumulative effects on
2 recreation (Section 4.17.3.10) are also relevant to this discussion.

3
4 The GCNP Backcountry and Fire Management Plan would tend to benefit visitor use and
5 experience under all the LTEMP alternatives through the protection of wilderness and visual
6 resources and soundscapes, while mitigating to some extent visitor effects on the same resources.

7
8 The 2006 CRMP, which regulates commercial and noncommercial boating and rafting,
9 would also tend to enhance visitor experience while protecting natural and cultural resources. By
10 limiting the number of rafters on the river, this plan would protect wilderness experience and
11 solitude. The 2010 Abandoned Mine Closure Plan could also enhance wilderness experience and
12 protect natural resources through restoration of a more natural state. Similarly, the 2012
13 withdrawal of approximately a million acres of federal land in the vicinity of GCNP from entry
14 for uranium mining would enhance wilderness values regionally by limiting industrial
15 development in areas surrounding the parks.

16
17 With respect to foreseeable actions in the study area, the proposed Noise and Flight
18 management alternatives could have a substantial beneficial effect on wilderness values in
19 GCNP. The proposed Grand Canyon Escalade development on 420 acres near the confluence of
20 the Little Colorado and Colorado Rivers could have adverse effects on wilderness values and
21 experience in that area. Visitors seeking solitude or a wilderness experience could be adversely
22 affected by the visual and noise effects and the presence of infrastructure, which is incompatible
23 with the character of GCNP.

24
25 Basin-wide trends that could affect wilderness values and experience would be primarily
26 those related to climate change. Wilderness and wilderness experience would be adversely
27 affected to the extent that warming and reduced water availability promote the growth of
28 invasive and nonnative species, which would alter the native character of vegetation. Low water
29 availability could cause crowding and loss of solitude on the river due to reduced navigability
30 and delays at rapids from periodic low flows.

31
32 The LTEMP alternatives vary with respect to their impact on wilderness experience.
33 Disturbance from non-flow actions would occur under all alternatives; the most crowding at
34 rapids would occur under Alternative E; alternatives with greater fluctuations (e.g.,
35 Alternatives A, B, and E) could affect wilderness character. None of the alternatives would
36 significantly contribute to the cumulative impacts for this resource.

37 38 39 **4.17.3.11 Visual Resources**

40
41 The current condition of visual resources is described in Section 3.12; this reflects the
42 effects of past and present cumulative impacts on resources within the project area. Section 4.12
43 discussed the potential impacts of the various LTEMP alternatives on visual resources within the
44 project area. Visual resources within the shorelines and waters of the Colorado River between
45 Glen Canyon Dam and Lake Mead, the shorelines of Lake Powell and Mead, and the general
46 landscape of the area may also be affected by reasonably foreseeable actions and basin-wide

1 factors contributing to cumulative impacts, including the Lake Powell Pipeline Project, uranium
2 mining, the Grand Canyon Escalade development, water use, and climate change.

3
4 Increased water demands from population and industrial growth, coupled with conditions
5 brought on by climate change such as severe drought and higher temperatures, could lead to
6 lower Lake Powell reservoir levels. In addition, the Lake Powell Pipeline Project would likely
7 result in slightly lower Lake Powell reservoir levels (UBWR 2011a,b). Additional impacts could
8 result from the pipeline alignment, proposed facilities, and transmission lines associated with the
9 Lake Powell Pipeline Project. No new infrastructure is proposed by any of the LTEMP
10 alternatives; however, if water is transferred to Sand Hollow Reservoir from Lake Powell, the
11 water level in Lake Powell could become lower, resulting in a slight increase in the height of the
12 calcium-carbonate ring that surrounds Lake Powell and increasing the exposure of sediment
13 deltas. These actions could also slightly increase the months of exposure of Cathedral-in-the-
14 Desert.

15
16 Uranium mining operations have the potential to change the landscape character in the
17 project area. The Grand Canyon Escalade development project includes a gondola, riverwalk,
18 amphitheater, visitor center, and retail complex. The development would be visible from six of
19 the seven eastern viewpoints in GCNP (Confluence Partners, LLC 2012b) and would cause a
20 visual contrast with the surrounding natural environment of the Grand Canyon and Colorado
21 River. Impacts on the landscape under the proposed LTEMP action are negligible and are not
22 expected to contribute to cumulative impacts affecting the landscape character.

23 24 25 **4.17.3.12 Hydropower**

26
27 Power operations and power marketing as they relate to Glen Canyon Dam and the Glen
28 Canyon powerplant are described in Section 3.13; Section 4.13 presented the potential impacts
29 that change in dam operations under the LTEMP alternatives would have on the economic value
30 of hydropower resources and on electricity capacity expansion necessary for the eight largest
31 Western customer utilities to replace lost hydropower generation, as well as the resulting impacts
32 on retail electricity rates charged by the eight largest customer utilities. Increased demand for
33 electricity in the service territories of the eight largest Western customer utilities and planned
34 retirement of existing powerplant generating capacity would require an estimated 4,820 MW of
35 new capacity to be built over the next 20 years (Section 4.13).

36
37 The incremental impact of the LTEMP alternatives generating capacity over the 20-year
38 period would be relatively small (<1% of baseline) and variable. Changes in operations at Glen
39 Canyon Dam (relative to current baseline conditions under Alternative A) would reduce
40 available generating capacity at Glen Canyon Dam under all LTEMP alternatives except
41 Alternative B. This reduction in capacity would be replaced by purchases from other sources or
42 construction of new capacity. Since the implementation of MLFF, between 1997 and 2005, the
43 average annual costs associated with these reductions have ranged from \$38 million to
44 \$50 million, due to operational restrictions (Veselka et al. 2010).

1 The LTEMP alternatives vary with respect to hydropower production, hydropower
2 capacity, and retail rates, and therefore cumulative impacts. Alternatives with higher fluctuation
3 levels (Alternatives A, B, D, and E) achieve higher values of generation and capacity and lower
4 impacts on retail rates than do alternatives with steadier flows (Alternatives C, F, and G),
5 especially if more water is released in the high-demand months of July and August.
6 Alternatives A and B would have the least effect on the value of generation, the value of
7 capacity, and retail rates, while Alternatives F and G would have the highest.

8 9 10 **4.17.3.13 Socioeconomics and Environmental Justice**

11
12 Actions and basin-wide trends contributing to cumulative impacts in the project area
13 (including Lake Powell, Lake Mead, and the stretch of the Colorado River between them) are
14 those that affect the economic valuation of its recreation resources and its recreational visitation
15 and expenditure rates. Those actions and trends having a high, adverse, and disproportionate
16 impact on minority and low-income populations are also of concern. The most significant trends
17 affecting recreation are those related to climate change (decreased water supply and drought),
18 because they have a direct effect on lake levels (exposed beaches and mudflats) and the seasonal
19 timing of fluctuations in river flow. Regional economics (i.e., expenditures by visitors) for
20 various types of recreational activities, including angling, rafting, and boating, as well as
21 expenditures on gasoline (for vehicles and boats), camping fees or motel expenses, guide
22 services, and fishing license fees are somewhat controlled by NPS regulations; the number of
23 boating trips are controlled as specified in the CRMP and the Comprehensive Fisheries
24 Management Plan cited in Table 4.17-1. These are not expected to change significantly under
25 any of the LTEMP alternatives.

26
27 The impact analysis determined on the basis of the 2010 Census that minority or low-
28 income populations exist in some block groups within San Juan (Utah) and Coconino (Arizona)
29 counties (Section 4.14.2.4). Impacts on Tribes are associated with alternatives that incorporate
30 frequent trout control actions (Alternatives C, D, and G), which affect Tribal values, or result in
31 increased economic impacts on Tribes associated with the cost of electricity (especially
32 Alternatives F and G).

33 34 35 **4.17.3.14 Air Quality and Climate Change**

36
37 The current condition of local and regional air quality is described in Section 3.15;
38 Section 4.15 presented the potential impacts of the LTEMP alternatives on visibility within the
39 project area (GCNP and the six-state area). Air quality is affected by air emissions from both
40 natural (e.g., wildfires and windblown dust) and manmade (e.g., power generation from fossil
41 fuel-fired plants) sources. The primary cause of visibility degradation in the region is the
42 scattering and absorption of light by fine particles. Other important contributors to visibility
43 degradation include combustion-related sources, fugitive dust sources, and particulate organic
44 matter. Emissions of SO₂ and NO_x from fossil fuel combustion are the major manmade causes of
45 visibility impairment; these emissions have been substantially reduced in the six-state area in the
46 past decade in response to state and federal requirements (Section 3.15.2).

1 The construction of new powerplants (and the renewal of existing coal-fired plants
2 permits) to meet energy demands from population and industrial growth in the region, coupled
3 with drought conditions brought on by climate change that could increase the potential for
4 wildfires and dust storms, could increase visibility impacts in the foreseeable future. The natural
5 scattering of light would continue to be the main contributor to visibility impairment (haze) in
6 the region, including GCNP. Other significant contributors to visibility degradation include
7 wildfires, windblown dust, and emissions from metropolitan areas (automobiles, manufacturing,
8 coal-fired powerplants, and combustion sources like diesel engines).

9
10 Although hydropower generation at Glen Canyon Dam does not generate air emissions,
11 dam operations can affect ambient air quality by causing a loss of generation that is offset by
12 generation from coal, natural gas, or oil units (Section 4.15.1). Under baseline operations
13 (Alternative A), emissions of SO₂ and NO_x would be about 10% and 3.0% of the total emissions
14 over the Western Interconnect region, respectively. Air quality impacts due to emissions under
15 the other alternatives would be negligible because they would be only slightly increased or
16 decreased relative to the baseline.

17
18 The EPA's Clean Power Plan Proposed Rule would have a beneficial impact on the air
19 quality in the region by mandating reductions in CO₂ emissions from fossil fuel-fired
20 powerplants (to 30% below 2005 levels by 2030). The closure of three coal-burning units at the
21 FCPP would also have a beneficial impact by reducing levels of NO_x and PM pollutants that
22 contribute to regional haze and visibility issues in the GCNP.

23
24 The incremental impact of the LTEMP alternatives on air quality over the 20-year period
25 is based on the emissions associated with power generation needed from other powerplants to
26 meet uninterrupted power demand of customers in the region. There is negligible difference in
27 the additional power generation needed among the alternatives (4,172 to 4,250 GWh per year);
28 the differences in SO₂ and NO_x precursor emissions are also negligible (Table 4.15-1).

29
30 GHG emissions under all the LTEMP alternatives can be compared to total U.S. GHG
31 emissions at 6,810.3 MMt CO₂e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions
32 relative to total U.S. GHG emissions are less than 1%, and range from 0.8089% (Alternative A)
33 to 0.8094% (Alternatives F and G). Therefore, potential impacts of dam operations on climate
34 change under the various alternatives are expected to be very small.

35 36 37 **4.18 UNAVOIDABLE ADVERSE IMPACTS**

38
39 On the basis of the assessments presented in Sections 4.1–4.17, each of the alternatives is
40 expected to result in some unavoidable adverse impacts on resources. These adverse impacts
41 result from the flow and non-flow actions included in each alternative and could be minimized
42 through adaptive management and implementation of mitigation measures.

43
44 All of the alternatives, including Alternative A, would result in continued reductions in
45 peak hydropower production relative to unconstrained release patterns that more closely match
46 generation with electrical demand due to restrictions on maximum and minimum flow, within-

1 day fluctuation levels, and ramping rates. Steady flow alternatives (Alternatives F and G) would
2 result in the greatest adverse impacts on hydropower value. Alternative B would result in an
3 increase in hydropower energy and capacity compared to Alternative A; Alternatives D and E
4 would produce less energy and capacity than Alternative A; Alternative C would produce less
5 than Alternatives D and E, but more than Alternatives F and G. Alternative F would produce less
6 energy and capacity than any of the alternatives.

7
8 Under all of the alternatives, sediment availability in the river channel below the dam
9 would continue to be limited due to the presence of the dam. No operational alternative can
10 reverse the reduction in sediment availability. Because of this sediment-depleted condition, all of
11 the alternatives would continue to produce a net loss of sand from the Colorado River ecosystem.
12 Alternatives C, D, E, F, and G retain more sandbars than Alternative A or Alternative B.

13
14 Implementation of mechanical removal of trout and TMFs would represent an
15 unavoidable adverse impact on certain Tribes if these actions are needed to manage the trout
16 fishery and mitigate trout impacts on humpback chub, because these actions are not in keeping
17 with important Tribal values. The adverse impacts of mechanical removal could be mitigated
18 with the provision of beneficial use (e.g., making euthanized fish available for human
19 consumption). Any other mitigation to avoid adverse impacts would need to be identified in
20 discussion with the Tribes.

21
22 The remaining unavoidable adverse impacts on certain resources are those associated not
23 with the alternatives themselves; instead, they are consequences of existing constraints on
24 operations (i.e., requirements of the Law of the River and the 2007 Interim Guidelines;
25 Reclamation 2007a), and the presence of Glen Canyon Dam and current dam infrastructure. For
26 example, temperature and sediment impacts of all alternatives are related to the inability of
27 operations themselves to provide for warmer temperatures or restore sediment supplies.
28 Infrastructure changes, which are not within the scope of the LTEMP DEIS, could mitigate those
29 impacts; however, without that infrastructure, these adverse impacts are unavoidable.

30 31 32 **4.19 RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM** 33 **PRODUCTIVITY**

34
35 Under all alternatives, different restrictions on flow fluctuations result in tradeoffs
36 between peak hydropower production and productivity of the environment, which is largely
37 related to increased nearshore habitat stability, aquatic food base productivity, and sandbar
38 building downstream from the dam. For example, alternatives that have increased flow
39 fluctuations or uneven monthly release volumes, such as Alternatives A and B, benefit peak
40 hydropower energy and capacity and other resources (such as humpback chub) but result in less
41 habitat stability and sandbar building. Alternatives with steady flows, such as Alternatives F
42 and G, have the greatest reduction in peak hydropower energy and capacity, but result in more
43 habitat stability and sandbar building downstream from the dam, and corresponding benefits for
44 other resources such as recreation, aquatic food base, and trout. As a result, each of the
45 alternatives presents a different balance between impacts on resources that appear to benefit from
46 increased fluctuations and those that benefit from reduced fluctuations. Alternatives C, D, and E

1 represent alternatives with more even monthly release volumes, and in the case of Alternatives C
2 and D, fluctuation levels that are comparable to or lower than those under Alternative A. These
3 alternatives strike a more even balance among resource impacts. However, regardless of the
4 alternative, experimental flow and non-flow actions associated with alternatives (e.g., HFEs,
5 TMFs, mechanical trout removal) would be tested in an attempt to maintain a balance that
6 improves long-term productivity of the environment downstream of Glen Canyon Dam.
7 Similarly, experimental elements of the alternatives are designed to improve our understanding
8 of how resources respond to operations and how management actions can be best used to avoid,
9 minimize, or mitigate impacts on resources and the long-term productivity of resources analyzed
10 in the LTEMP DEIS.

11
12

13 **4.20 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES**

14

15 Any experiment or operation that bypasses Glen Canyon Dam generators (e.g., HFEs that
16 exceed powerplant capacity through generator bypass), or flows that reduce flexibility for
17 peaking power (e.g., lower summer flows), cause an irretrievable loss of hydropower production.
18 In addition, some air quality impacts would occur under alternatives that alter the energy and
19 capacity generated by Glen Canyon Dam, because these changes would necessitate generation
20 from fossil-fuel-fired powerplants to offset loss and early construction of new generating
21 capacity. No other instances of irreversible or irretrievable commitments of resources are
22 expected under any of the alternatives. Although operations, flow actions, non-flow actions, and
23 experiments could result in unexpected impacts on natural and cultural resources, a long-term
24 monitoring program implemented as part of the ongoing Glen Canyon Dam Adaptive
25 Management Program would be used to inform the need for changes in operations and actions to
26 minimize impacts and prevent further impacts on important resources. Safeguards have been
27 incorporated into alternatives, including implementation considerations that would preclude
28 taking specific actions if implementation would result in unacceptable adverse impacts, and off-
29 ramps that would be used to alter operations or stop actions to prevent irreversible losses.

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1 entities, five state agencies, and six Tribes, are listed in Table 5.1-1, along with descriptions of
2 their participation.

3
4 All Cooperating Agencies have had the opportunity to participate in regular meetings and
5 workshops and webinars related to the development of this DEIS, participate in monthly
6 meetings with the joint leads, and review and comment on the DEIS. Beginning in
7 February 2012, the Cooperating Agencies met every month during the preparation of the DEIS.
8 In addition, more than 30 meetings, workshops, and webinars were conducted with stakeholders
9 and Cooperating Agencies to assist in the development of alternatives and performance
10 measures, conduct the Structured Decision Analysis (SDA), and provide general status updates.
11 Federal Cooperating Agencies (i.e., Bureau of Indian Affairs [BIA], U.S. Fish and Wildlife
12 Service [FWS], and Western Area Power Administration [Western]) also participated in the
13 process of alternative development for the DEIS.

14 15 16 **5.1.3 American Indian Tribes**

17
18 As part of the government's Treaty and Trust responsibilities, the Federal Government
19 works on a government-to-government basis with American Indian Tribes. The government-to-
20 government relationship and the process for developing open and transparent communication,
21 effective collaboration, and informed federal decision-making with Indian Tribes was identified
22 in Executive Order (E.O.) 13175, "Consultation and Coordination with Indian Tribal
23 Governments" (U.S. President 2000); E.O. 13007, "Indian Sacred Sites" (U.S. President 1996);
24 Secretarial Order (S.O.) 3206, "American Indian Tribal Rights, Federal-Tribal Trust
25 Responsibilities, and the Endangered Species Act" (DOI 1997); S.O. 3317, "Department of the
26 Interior Policy on Consultation with Indian Tribes" (DOI 2011a); and the President's
27 "Memorandum on Government-to-Government Relations with Native American Tribal
28 Governments" (U.S. President 1994a). In addition, Section 106 of the National Historic
29 Preservation Act (NHPA) requires federal agencies to consult with Indian Tribes on undertakings
30 on Tribal lands and on historic properties of significance to the Tribes that may be affected by an
31 undertaking (36 CFR 800.2 (c)(2)). Both Reclamation and NPS coordinate and consult with all
32 Tribal governments, Native American communities and organizations, and Tribal individuals
33 whose interests might be directly and substantially affected by activities within their jurisdiction.

34
35 Government-to-government consultation has been and will continue to be conducted
36 throughout development of this DEIS, in accordance with provisions of the Executive Orders and
37 Secretarial Orders listed above as well as Section 106 of the NHPA, and any additional
38 applicable natural and cultural resource laws (e.g., NEPA, the Endangered Species Act [ESA],
39 NHPA, and Migratory Bird Treaty Act), as well as agency-specific guidance, such as:

- 40
41 • DOI, Departmental Manual, *Departmental Responsibilities for Indian Trust*
42 *Resources*, 512 DM 2 (1995).
- 43
44 • DOI, Departmental Manual, *Departmental Responsibilities for Protecting/*
45 *Accommodating Access to Indian Sacred Sites*, 512 DM 3 (1998).

1 **TABLE 5.1-1 Summary of Cooperating Agency Involvement**

Cooperating Agency	Type	Summary of Involvement
Arizona Game and Fish Department (AZGFD)	State	AZGFD is a Cooperating Agency in recognition of its role in conserving, enhancing, and restoring Arizona’s diverse wildlife resources and habitats. AZGFD is also a member of the Glen Canyon Dam Adaptive Management Working Group (AMWG). AZGFD participated in several stakeholder meetings, and representatives offered expertise during development of resource goals, performance metrics, and the aquatic modeling approach.
Bureau of Indian Affairs (BIA)	Federal	BIA is a Cooperating Agency in recognition of its administration of federal trust responsibility to Indian Tribes. BIA assisted in government-to-government consultations and served in an advisory capacity to Reclamation and the Indian Tribes.
Colorado River Board of California (CRBC)	State	CRBC is a Cooperating Agency in recognition of its responsibility for maintaining or increasing the quantity of California's Colorado River water resources. CRBC is also a member of the Glen Canyon Dam AMWG and represents California as part of the group of seven Basin States that have interests in the Colorado River. CRBC contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.
Colorado River Commission of Nevada (CRCN)	State	CRCN is a Cooperating Agency in recognition of its responsibility for acquiring and managing water and hydropower resources from the Colorado River. CRCN is also a member of the Glen Canyon Dam AMWG and represents Nevada as part of the group of seven Basin States that have interests in the Colorado River. CRCN contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.
The Havasupai Tribe	Tribe	The Havasupai Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. Havasupai representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and have contributed written portions to the DEIS.
The Hopi Tribe	Tribe	The Hopi Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and Technical Work Group (TWG). Hopi representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the DEIS.

2

TABLE 5.1-1 (Cont.)

Cooperating Agency	Type	Summary of Involvement
The Hualapai Tribe	Tribe	The Hualapai Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Hualapai representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the DEIS.
The Kaibab Band of Paiute Indians	Tribe	The Kaibab Band of Paiute Indians is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Kaibab representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values and provided comments on performance metrics and resource goals.
The Navajo Nation	Tribe	The Navajo Nation is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Navajo representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and provided comments on performance metrics and resource goals.
The Pueblo of Zuni	Tribe	The Pueblo of Zuni is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. Zuni representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the DEIS.
Salt River Project (SRP)	Public Utility	SRP is a Cooperating Agency in recognition of its role as one of the primary public utility companies in Arizona. SRP participated in several Cooperating Agency and stakeholder meetings and provided comments on performance metrics and modeling results.
Upper Colorado River Commission (UCRC)	Inter-State	UCRC is a Cooperating Agency in recognition of its role as part of the group of seven Basin States that have interests in the Colorado River. UCRC is also a Glen Canyon Dam AMWG member. UCRC contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.

TABLE 5.1-1 (Cont.)

Cooperating Agency	Type	Summary of Involvement
U.S. Fish and Wildlife Service (FWS)	Federal	The FWS is a Cooperating Agency in recognition of its jurisdiction by law and special expertise with respect to the ESA and biological resources within the study area. FWS has participated in the formation and development of LTEMP resource goals and objectives, performance metrics and alternatives, as well as the development of the aquatic modeling approach. In addition, a representative from FWS serves as the Tribal Liaison and has participated in government-to-government meetings with the Tribes.
Utah Associated Municipal Power Systems (UAMPS)	Public Utility	UAMPS is a Cooperating Agency in recognition of its role as a purchaser of electricity from the Colorado River Storage Project. UAMPS is also a member of the AMWG. UAMPS participated in Cooperating Agency and stakeholder meetings and provided comments on the performance metrics.
Western Area Power Administration (Western)	Federal	Western is a Cooperating Agency in recognition of its role in marketing and transmitting electricity from the Glen Canyon Dam. Western representatives participated in the development of alternatives and hydropower performance metrics and provided funds for the hydropower systems analysis.

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- DOI, Order No. 3317, *Policy on Consultation with Indian Tribes*, December 1, 2011 (DOI 2011a).
- Reclamation, *Indian Policy of the Bureau of Reclamation*, 1998 (revised 2001).
- Reclamation, *Protocol Guidelines, Consulting with Indian Tribal Governments*, 2001 (Reclamation 2012g).
- *Programmatic Agreement among the Bureau of Reclamation, the Advisory Council on Historic Preservation, the National Park Service, the Arizona State Historic Preservation Officer, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Navajo Nation, San Juan Southern Paiute Tribe, Shivwits Paiute Tribe, and Zuni Pueblo Regarding the Operation of Glen Canyon Dam*, 1994 (Reclamation 1994).
- NPS, *Management Policies 2006* (NPS 2006d).

On November 30, 2011, 43 Tribes, bands, and organizations were formally invited to enter into government-to-government consultation on the LTEMP DEIS. The letters, sent by the joint-lead agencies, provided notification of the intent to prepare the LTEMP DEIS; initiated government-to-government consultation; and invited the Tribes to identify concerns related to

1 historic properties, including traditional cultural properties and archaeological sites, natural
2 resources, relevant Indian Trust assets, and other issues of importance.

3
4 A total of 31 Tribes responded to the invitation. Six Tribes agreed to participate as
5 Cooperating Agencies (see Section 5.1.2); three Tribes (the Fort Mojave Tribal Council, Pueblo
6 of Zia, and Gila River Indian Community) agreed to participate as Consulting Tribes; eight
7 Tribes (Pueblo of Santa Clara, Ute Indian Tribe, Ute Mountain Ute, Pueblo of Nambe, Yavapai
8 Apache, Paiute Indian Tribe of Utah, the Pueblo of Santa Ana, and the Fort Yuma Quechan)
9 declined participation, but asked to remain on the mailing list; and 14 Tribes (Ak Chin Indian
10 Community, Cocopah Indian Tribe, Fort McDowell Yavapai Tribal Council, Jicarilla Apache
11 Nation, Ohkay Owingeh, Southern Ute Tribal Council, the Pueblo of Acoma, the Pueblo of
12 Laguna, the Pueblo of Sandia, Yavapai-Prescott Indian Tribe, Chemehuevi Tribal Council,
13 Tohono O’odham Nation, the Pueblo of Pojoaque, and the White Mountain Apache) declined
14 participation in the LTEMP DEIS. The joint leads have yet to receive a response to the request
15 for consultation from the remaining 12 Tribes (Colorado River Indian Tribes, Las Vegas Tribe of
16 Paiute Indians, Moapa Band of Paiute Indians, Salt River Pima-Maricopa Indian Community,
17 San Carlos Apache Tribe, San Juan Southern Paiute Tribe, the Pascua Yaqui Tribe, the Pueblo
18 of Cochiti, the Pueblo of Jemez, the Pueblo of San Felipe, the Pueblo of Tesuque, and
19 Tonto Apache).

20
21 Cooperating and consulting Tribes were invited to attend meetings, workshops, and
22 webinars, and to review various documents related to the development of the LTEMP DEIS. A
23 series of workshops, conference calls, and webinars were held with Tribes to identify Tribal
24 resource goals and ways to measure the relative performance of alternatives against those goals.
25 A list of major face-to-face meetings, webinars, and conference calls involving Tribes is
26 provided in Appendix N, Table N-2. Meeting notes and other important documents related to the
27 LTEMP DEIS development process were sent to those Tribes who wished to remain on the
28 mailing list. Reclamation and NPS will continue to provide consultation opportunities for
29 interested Tribes and keep all Tribal entities informed about the NEPA process for the DEIS. A
30 full summary of Tribal communication as of March 2015 is provided in Appendix M.

31 32 33 **5.1.4 Other Consultations**

34 35 36 **5.1.4.1 National Historic Preservation Act (NHPA)**

37
38 Section 106 of the NHPA of 1966, as amended, and its implementing regulations,
39 requires federal agencies to address the effect of projects on historical properties (i.e., resources
40 determined eligible or listed on the *National Register of Historic Places* [NRHP]) and to give the
41 State Historic Preservation Officers (SHPOs), Advisory Council on Historic Preservation
42 (ACHP), and Traditionally Associated American Indian Tribes, as necessary, a reasonable
43 opportunity to comment on such effects. Reclamation has the lead for Section 106 compliance
44 and initiated the process of consultation with the Arizona SHPO. Consultations regarding
45 eligibility of cultural resources to the NRHP and the effect of the proposed federal action are
46 ongoing. In addition, consultations occurred with Tribal Historic Preservation Officers and

1 Indian Tribes with concerns under E.O. 13007, “Indian Sacred Sites” (U.S. President 1996), the
2 Native American Graves Protection and Repatriation Act, and Section 106 of the NHPA.

3
4 On November 30, 2011, 43 Tribes, bands, and organizations were formally invited to
5 enter into government-to-government consultation on the LTEMP DEIS (see Section 5.1.3). As
6 part of the consultation process for this DEIS, Reclamation will continue to identify concerns,
7 assess the potential for cultural resources impacts, develop appropriate mitigation measures, and
8 seek concurrence with the determination of effect. If adverse effects are identified, Reclamation
9 would continue consultation to seek options to avoid, minimize, or mitigate the adverse effects
10 on historic properties. Reclamation, in consultation with interested parties, is developing a
11 Programmatic Agreement to address any cultural resource effects and mitigation measures.

12 13 14 **5.1.4.2 State and Local Water and Power Agency Coordination**

15
16 Reclamation and NPS have had various discussions with state and local water agencies
17 regarding the proposed federal action. The seven Basin States in particular have been
18 continuously engaged throughout the scoping and alternatives development processes. This
19 engagement has consisted of conference calls, webinars, and face-to-face meetings to discuss
20 process, resource goals, alternative characteristics, metrics to determine the relative performance
21 of alternatives against those metrics, and the overall modeling approach used to quantify
22 impacts.

23
24 One of the alternatives considered in the LTEMP DEIS (Alternative E) was developed by
25 the Basin States (as the Resource-Targeted Condition-Dependent Alternative) and submitted to
26 the joint-lead agencies. The joint-lead agencies shared initial impact analysis results and insights
27 that were ultimately used by the Basin States to further refine Alternative E.

28
29 The Colorado River Energy Distributors Association (CREDA) is an organization that
30 represents consumer-owned electric systems that purchase federal hydropower and resources of
31 the Colorado River Storage Project. While not a Cooperating Agency, CREDA, a member of the
32 Glen Canyon Dam Adaptive Management Work Group (AMWG), submitted Alternative B, and
33 Reclamation and NPS worked closely with CREDA to define and model resource effects of this
34 alternative. CREDA has also participated in stakeholder meetings and provided comments on the
35 performance metrics.

36 37 38 **5.1.4.3 U.S. Fish and Wildlife Service (FWS)**

39
40 FWS participated in the formation and development of LTEMP alternatives, providing
41 expertise in several workshops and webinars. FWS also worked with the joint-lead agencies and
42 subject matter expert groups in the development of resource goals and objectives and
43 performance metrics to evaluate the alternatives. FWS provided expertise during the
44 development of the aquatic modeling approach used in this DEIS.

1 Reclamation and NPS consulted with FWS on the effects of the LTEMP on species listed
2 under Section 7 of the ESA. This consultation was a continuation of ongoing consultation that
3 has occurred since 1995. Reclamation has consulted with the FWS on a total of five experimental
4 actions. The Biological Opinion prepared for the LTEMP will supersede the 2011 opinion on the
5 high-flow experimental protocol and nonnative fish protocols.
6
7

8 **5.2 PUBLIC INVOLVEMENT**

9

10 Public involvement in the NEPA process is intended to give the public the chance to
11 provide input throughout the development of a DEIS and the decision-making process for actions
12 with environmental effects. An objective of public involvement is to obtain information from the
13 public to assist the decision-maker (Secretary of the Interior) throughout the entire process,
14 culminating in a Record of Decision and eventual implementation of the selected alternative. The
15 primary goals of public involvement are:
16

- 17 1. *Credibility and transparency*: creating an open and visible decision-making
18 process for groups with divergent viewpoints.
- 19 2. *Identifying public concerns and values*: providing a mechanism by which the
20 involved agencies can understand the problems, issues, and possible solutions
21 from the perspectives of the public.
22
- 23 3. *Developing a consensus*: providing a process for reaching a consensus on
24 specific actions.
25
26

27 In order to identify issues, address public concerns, obtain public input, and keep the
28 public informed, several opportunities were provided for public participation during the
29 preparation of this DEIS. These included an early and open public scoping process and public
30 meetings related to development of preliminary alternatives. The public scoping process is
31 described below in Section 5.2.1.
32
33

34 **5.2.1 Public Scoping Process and Comments Received**

35

36 The process of soliciting input from the public is called scoping. Public scoping is a
37 phase of the NEPA analysis process and was intended to give the public the chance to comment
38 on the LTEMP, recommend alternatives, and identify and prioritize the resources and issues to
39 be considered in the DEIS analyses. Consistent with CEQ requirements (40 CFR 1501.7) and
40 DOI NEPA regulations at 43 CFR Part 46, an early and open public scoping process was carried
41 out to determine the resources or issues to be evaluated in the LTEMP DEIS, the alternatives to
42 be included in the LTEMP DEIS, and concerns or observations regarding Glen Canyon Dam
43 operations and downstream resources. Reclamation and NPS have considered the public scoping
44 comments in developing this DEIS.
45

1 Reclamation and NPS published a Notice of Intent (NOI) to prepare the LTEMP DEIS in
2 the *Federal Register* (Volume 76, page 39435) on July 6, 2011 (DOI 2011b). The NOI provided
3 initial information on the purpose and need of the LTEMP DEIS, explained the decision for
4 Reclamation and NPS to co-lead the project, and encouraged the participation of stakeholders in
5 the development of the LTEMP DEIS. The public scoping period started with the publication of
6 the NOI and ended on January 31, 2012.

7
8 Early in the scoping process, Reclamation and NPS established a website for the LTEMP
9 DEIS (<http://ltempeis.anl.gov>) that provided background information about the project,
10 information on public involvement, answers to frequently asked questions, and links to
11 documents for review. During the public scoping process, a link to the project's online comment
12 form was provided and made available on the NPS's Planning, Environment, and Comment
13 website. In addition, project updates and announcements were made available via an email
14 subscription list, press releases, and social media (e.g., Twitter and Facebook).

15
16 "A Notice to Solicit Comments and Hold Public Scoping Meetings on the Adoption of a
17 Long-Term Experimental and Management Plan for the Operation of Glen Canyon Dam" was
18 published in the *Federal Register* (Volume 76, page 64104) on October 17, 2011 (DOI 2011c),
19 which provided the date, time, and place for six public meetings to be held to solicit public input
20 on the scope of the DEIS, including potential alternatives and issues to be addressed within the
21 document. Meetings were held in the following locations:

- 22 • Phoenix, Arizona (November 7, 2011)
- 23 • Flagstaff, Arizona (November 8, 2011)
- 24 • Page, Arizona (November 9, 2011)
- 25 • Salt Lake City, Utah (November 15, 2011)
- 26 • Las Vegas, Nevada (November 16, 2011)
- 27 • Lakewood, Colorado (November 17, 2011)

28
29 The notice also indicated that there would be one web-based public meeting
30 (November 15, 2011) for those who could not attend in person. The public was also notified of
31 the meetings via a press release, local media outlets, and an op-ed article disseminated for
32 publication in local and regional newspapers.

33
34 At the public meetings, the public could view exhibits about the project, discuss issues
35 informally and ask questions of technical experts and managers. A total of 221 people attended
36 these meetings. For the web-based meeting, the public was able to listen to, via the Internet, a
37 live overview presentation of the LTEMP DEIS and to ask questions of technical experts and
38 managers.

1 A total of 447 individuals, recreational groups, environmental groups, power customers
2 or organizations, federal and state government agencies, and other organizations provided
3 scoping comments on the LTEMP DEIS. Although no formal campaign letters were received,
4 some commenters chose to incorporate in their submissions entire letters or portions of letters
5 from various other commenting organizations.
6

7 Comments received during the public scoping period covered a wide range of topics and
8 issues and represented a variety of views and interpretations. Comments addressed various
9 aspects of the proposed action, including the purpose and need (as stated in the July 6, 2011, NOI
10 [DOI 2011b]); environmental issues; dam operations and hydropower; geographic and temporal
11 scope; policy and regulatory concerns; LTEMP approach and considerations; alternatives; other
12 issues; and stakeholder involvement. A detailed summary of comments received can be found in
13 *Summary of Public Scoping Comments on the Glen Canyon Dam Long-Term Experimental and*
14 *Management Plan Environmental Impact Statement* (Argonne 2012), available on the LTEMP
15 website (<http://ltempeis.anl.gov>).
16

17 In general, the most frequent topic for comments on the LTEMP DEIS was related to
18 environmental issues. Comments and concerns frequently raised by the public included
19 restoration of the downstream Colorado River ecosystem; reestablishment of ecosystem patterns
20 and processes to their pre-dam range of natural variability; elimination or minimization of further
21 beach erosion; facilitation of sediment redeposition; in situ maintenance and preservation of the
22 integrity of cultural and archeological resources; elimination of adverse impacts on and
23 assistance in the recovery of native species; nonnative fish management; and assistance in
24 repropagation of native riparian plant communities.
25
26

27 **5.2.2 Public Meetings on Alternatives**

28
29 Members of the public were invited to participate in a 2-day open public meeting on
30 preliminary alternative concepts, hosted by Reclamation and the NPS. The meeting was held on
31 April 4 and 5, 2012, at the High Country Conference Center in Flagstaff, Arizona. More than
32 70 people attended the meeting, including members of the public, stakeholders, and project staff
33 from Reclamation, NPS, and Argonne.
34

35 During this meeting, alternatives being considered for inclusion in the LTEMP DEIS
36 were presented and discussed. Stakeholders and other attendees who had alternatives to propose
37 were able to present those ideas at the meeting; four individuals representing different
38 stakeholder groups presented their ideas. Following the presentations, meeting attendees broke
39 into smaller groups and focused on evaluating and refining the preliminary alternative concepts.
40 These small groups reported their discussions in an open forum during the meeting.
41

42 Reclamation and NPS evaluated the feedback received at this meeting and used it to
43 develop the final set of alternatives considered in this DEIS (discussed in detail in Chapter 2).
44 Maintaining that all alternatives meet the purpose and need of the proposed action, this
45 evaluation resulted in new alternative concepts, the modification of existing concepts, and the
46 combination of some concepts into single alternatives.

1 Regular updates of the LTEMP DEIS process were provided at public meetings of the
2 Glen Canyon Dam AMWG. LTEMP DEIS joint leads regularly presented the status of
3 preliminary DEIS-related materials (e.g., purpose and need, resource goals, and preliminary draft
4 alternatives) and coordination activities with the Cooperating Agencies. These meetings are
5 described in more detail in Section 5.2.3.
6
7

8 **5.2.3 Glen Canyon Dam Adaptive Management Working Group** 9

10 The Glen Canyon Dam AMWG is a federal advisory committee. As an advisory
11 committee, the AMWG has provided a forum for discussion of key issues related to the operation
12 of Glen Canyon Dam among the federal agencies, Indian Tribes, environmental groups,
13 recreational interest groups, federal power purchase contractors, and other stakeholders who
14 have interests in the resources of the Colorado River. AMWG members meet several times
15 throughout the year to discuss competing issues on how to protect downstream resources and
16 strike a wise balance on river operations. Their recommendations are regularly provided to the
17 Secretary by the Secretary's Designee, who often brings these competing issues to a consensus
18 (Reclamation 2014d).
19

20 Separate meetings regarding the LTEMP DEIS have been held with the Glen Canyon
21 AMWG because of its status as a Federal Advisory Committee. These meetings occurred on
22 February 18–22, 2013, May 8, 2013, August 8–9, 2013, February 18–20, 2014, May 27, 2014,
23 August 27–28, 2014, February 25–26, 2015, and May 28, 2015. These meetings were conducted
24 to provide an explanation of alternatives, performance criteria, and SDA; conduct swing-
25 weighting exercises; answer budget questions; and provide general status updates.
26
27

28 **5.3 DISTRIBUTION OF THE LTEMP DEIS** 29

30 The LTEMP DEIS was mailed to Region 9 of the U.S. Environmental Protection Agency
31 and to each of the Governors, Senators, and Representatives from relevant Congressional
32 districts of the seven Colorado River Basin States (Arizona, California, Colorado, Utah, Nevada,
33 New Mexico, and Wyoming). An email notification of the availability of the DEIS for download
34 from the project website (www.ltempeis.gov) was sent to approximately 600 members of the
35 public who had signed up for notification during the scoping period.
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7 LIST OF PREPARERS

This chapter presents information on the preparers of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Draft Environmental Impact Statement (DEIS). The list of preparers is organized by agency or organization, and information is provided on education, experience, and contribution to the LTEMP DEIS.

Name	Education/Experience	Contribution
Bureau of Reclamation		
Mary Barger	B.A., Anthropology; 36 years of federal archaeology and Section 106 experience. Upper Colorado Region/Archaeologist.	Reclamation lead for cultural and Tribal resources
Alan Butler	B.S./M.S., Civil Engineering; 6 years experience in civil engineering. Lower Colorado Region, Hydrologic Engineer.	Technical analyst and subject matter expert, reservoir operations and hydrology; reservoir modeling
Rick Clayton	B.S., Civil Engineering; B.S., Environmental Economics; 14 years experience in reservoir operations; 3 years experience in powerplant operations. Upper Colorado Region General Engineer.	Reclamation lead for power resource analysis; hydrology and reservoir modeling
Todd Gaston	M.S. Resource Economics; B.S. Environmental Science; 7 years experience in natural resources management and economics. Technical Service Center, Economics and Resource Planning Team.	Technical analyst and subject matter expert, socioeconomics, recreational economics
Katrina Grantz	Ph.D., Civil Engineering; 14 years experience in water resources research, hydrology, and decision support systems; 8 years experience in reservoir operations. Upper Colorado Region/Hydraulic Engineer.	Lead author of Section 4.2 (water resources) and Appendix D, technical lead for reservoir operations and hydrology; reservoir modeling
Dave Harpman	Ph.D., Natural Resource Economics; MSc., Agricultural Economics; BSc., Fisheries Management; 24 years experience. Technical Service Center Natural Resource Economist.	Technical lead for recreational economics; subject matter expert, socioeconomics
Beverley Heffernan	B.A., History; 30 years experience in NEPA compliance. Upper Colorado Region/Manager, Environmental Resources Division.	Co-lead EIS project manager

Name	Education/Experience	Contribution
Jianchun “Victor” Huang	Ph.D., Civil Engineering; 14 years experience in hydraulics and sediment transport. Technical Service Center, Sedimentation and River Hydraulics Group, Hydraulic Engineer.	Technical analyst and subject matter expert, sediment resources; sediment modeling
Glen Knowles	M.S., Zoology; 20 years experience in aquatic ecology, fisheries biology, and conservation biology. Upper Colorado Region/Chief, Adaptive Management Group, Biologist.	Project management and review
Jim Prairie	Ph.D., Civil Engineering; 15 years experience in water resources research, hydrology, and salinity modeling, and decision support systems. Upper Colorado Region/Hydrologic Engineer.	Technical analyst and subject matter expert, reservoir operations and hydrology, climate change; reservoir modeling, water quality modeling
Kendra Russell	M.S., Geography and Environmental Engineering; B.S. Civil and Environmental Engineering; 6 years experience in water resources engineering. Technical Service Center, Sedimentation and River Hydraulics; Hydraulic Engineer.	Project management and review; subject matter expert, sediment resources and modeling
David Varyu	M.S., Civil Engineering; 9 years experience in hydraulic engineering and sediment transport. Technical Service Center, Sedimentation and River Hydraulics Group; Hydraulic Engineer.	Lead author of sediment resources sections (Section 4.3, Appendix E); technical lead, sediment resources; sediment modeling
Nick Williams	B.S., Civil and Environmental Engineering; M.S., Civil and Environmental Engineering; 5 years as an environmental engineer; 5 years as a water quality specialist. Upper Colorado Region/Water Quality Specialist.	Technical analyst and lead for temperature and water quality modeling
National Park Service		
Jan Balsom	M.A., Anthropology; 32 years experience in southwestern archaeology, Tribal relations, and Park Management. Grand Canyon National Park Deputy Chief for Science and Resource Management.	Project management and review; lead author of park operations and management section (Appendix O); subject matter expert for Grand Canyon cultural and Tribal resources, park management, and wilderness, natural processes, and hydropower

Name	Education/Experience	Contribution
Robert Billerbeck	M.S., Conservation Biology; 18 years experience in Natural Resource Management and Environmental Compliance. Intermountain Region Colorado River Coordinator.	Co-lead EIS project manager
Martha Hahn	M.S., Recreation Behavior; 38 years experience in resources and public land management. Grand Canyon National Park/Chief, Science and Resource Management.	Project management and review; subject matter expert for ecological resources
Jennifer Rebenack	M.S., Fisheries Biology; 8 years experience in fisheries and wildlife ecology and environmental compliance. Intermountain Region Colorado River Program Biologist.	Project management assistant
Argonne National Laboratory		
Jennifer Abplanalp	M.A., Anthropology; 13 years experience in cultural resources and 2 years experience in visual impact assessments.	Contributing author of Tribal and visual resources sections (Sections 3.9, 3.12, 4.9, 4.12; Appendix I); subject matter expert, Tribal resources, cultural resources, and visual resources; records management
Timothy Allison	M.S., Mineral and Energy Resource Economics; M.A., Geography; 24 years experience in regional analysis and economic impact analysis.	Lead author of hydropower and socioeconomics sections (Sections 3.13, 3.14, 4.14; Appendix L); technical analyst and lead for socioeconomic and environmental justice
Georgia Anast	B.A., Mathematics/Biology; over 20 years experience in environmental assessment.	Comment processing; administrative record
Kevin J. Beckman	B.S., Mathematics and Computer Science; 5 years experience in Web programming and visual impact analysis.	Public website development
Ron Black	B.S., Electronics Engineering; 20 years experience in programming.	Technical analyst vegetation modeling
Edward Bodmer	M.B.A., Econometrics; B.S., Finance; 30 years experience in utility ratemaking and financial analysis.	Contributing author of retail rate sections (Section 4.13, Appendix K.3); technical lead for retail rate impact analysis

Name	Education/Experience	Contribution
Young Soo Chang	Ph.D., Chemical Engineering; 24 years experience in air quality and noise impact analysis.	Lead author of air quality and climate change sections (Sections 3.15, 3.16, 4.15, 4.16; Appendix M); technical lead for air quality
Vic Comello	M.S., Physics; 38 years writing and editing experience.	Contributing editor
Mary Finster	Ph.D., Civil and Environmental Engineering; 8 years experience in health risk assessment.	Lead author of water and sediment resource sections (Sections 3.2, 3.3), and water quality section (Section 4.2); technical lead for water quality; public comment processing, scoping
Jessica Griffin	M.S., Historical Archaeology; 3 years experience in cultural resources assessments.	Project management assistant
John Hayse	Ph.D., Zoology; 27 years experience in ecological research and environmental assessment.	Lead author of aquatic resource sections (Sections 3.5, 4.5; Appendix F); technical lead for aquatic ecology; lead technical analyst temperature suitability modeling
Ihor Hlohowskyj	Ph.D., Zoology; 37 years experience in ecological research; 35 years in environmental assessment.	Lead author of natural processes sections (Sections 3.4, 4.4); contributing author of aquatic resource sections (Sections 3.5, 4.5; Appendix F); technical lead for natural processes subject matter expert, native and nonnative fish
Pat Hollopeter	B.A., Religion; M.A., Philosophy; 30 years experience editing technical communication products.	Contributing editor
Mark Jusko	M.S., Computer Science; 34 years experience in software engineering.	Hydropower and power systems modeling and graphics
Kirk E. LaGory	Ph.D., Zoology; M.S., Environmental Science; 38 years experience in ecological research; 28 years in environmental assessment.	Argonne EIS project manager; lead author of introduction and alternatives sections (Chapters 1 and 2) and Appendices A and B; contributing author of water resources and wildlife sections (Sections 4.2, 4.7)

Name	Education/Experience	Contribution
James E. May	M.S., Water Resources Management; B.A., Zoology; 32 years experience in natural resources management; 11 years of consulting experience in land use planning and NEPA compliance.	Contributing author of recreation sections (3.10, 4.10); subject matter expert recreation, visitor use and experience
Michele Nelson	Graphic designer; 36 years experience in graphic design and technical illustration.	Graphics
Daniel O'Rourke	M.S., Industrial Archeology; B.A. History and Anthropology; 19 years experience in archaeology.	Lead author of cultural resources sections (Sections 3.8, 4.8; Appendix H); technical lead for cultural resources; subject matter expert, Tribal resources
Terri Patton	M.S., Geology; 26 years experience in environmental research and assessment.	Lead author of cumulative impacts section (Section 4.17); subject matter expert geology, soil, sediment resources, and cumulative impacts
Kurt Picel	Ph.D., Environmental Health Sciences; 35 years experience in environmental health analysis and 20 years in environmental assessment.	Argonne EIS project management; lead author of recreation and wilderness sections (Sections 3.10, 4.10; Appendix J); contributing author of air quality and climate change sections (Sections 4.15, 4.16; Appendix M); subject matter expert for recreation, visitor use and experience, and wilderness
Leslie Poch	M.S., Nuclear Engineering; 30 years experience in power systems analysis and hydropower modeling.	Lead author of hydropower sections (Section 4.13, Appendix K.1); technical lead, hydropower modeling and power systems analysis
Carolyn M. Steele	B.A., English; B.A., Rhetoric; 9 years experience in technical writing and editing.	Lead editor
Robert Sullivan	M.L.A., Landscape Architecture; 25 years experience in visual impact analysis and simulation; 13 years in website development.	Lead author of visual resources section (Sections 3.12, 4.12); technical lead for visual resources
Jack C. Van Kuiken	M.S., Systems Science; 39 years experience in electrical power systems modeling, optimization, and analysis.	Technical analyst and subject matter expert, hydropower modeling and power systems analysis

Name	Education/Experience	Contribution
Robert Van Lonkhuyzen	B.A., Biology; 24 years experience in ecological research and environmental assessment.	Lead author of vegetation sections (Sections 3.6, 4.6; Appendix G); technical lead for vegetation
Bruce Verhaaren	M.A., Anthropology; Ph.D., Near Eastern Languages and Civilizations; 34 years experience in archaeological analysis; 24 years in environmental assessment and Tribal resources.	Lead author of Tribal resources sections (Sections 3.9, 4.9; Appendix I); technical lead for Tribal resources; subject matter expert, cultural resources; records management
Tom Veselka	M.S., Meteorology; 34 years experience in energy, power, and environmental systems modeling/optimization.	Contributing author of hydropower sections (Section 4.13; Appendix K.1); subject matter expert, hydropower modeling and power systems analysis
William S. Vinikour	M.S., Biology with environmental emphasis; 38 years experience in ecological research and environmental assessment.	Lead author food base (Sections 3.5, 4.5; Appendix F) and wildlife sections (Sections 3.7, 4.7); subject matter expert, aquatic food base and wildlife
Cory Weber	M.S., Operations Management and Information Systems; 9 years experience in research software and visualization development.	Technical analyst hydropower modeling
Kelsey Wuthrich	B.S., Civil and Environmental Engineering; 2 years experience in environmental science.	Technical analyst sediment, cultural, recreation, and water use modeling
Emily Zvolanek	B.A., Environmental Science; 6 years experience in GIS mapping	GIS mapping and analysis
U.S. Geological Survey		
Barbara Ralston	Ph.D., Botany; 28 years experience in floristics and 20 years experience in southwestern riparian ecology.	Lead technical analyst vegetation modeling
Michael C. Runge	Ph.D., Wildlife Science; 16 years experience in decision analysis, wildlife population modeling, statistical analysis, and ESA consulting; 5 years experience in NEPA assessment.	Lead author structured decision analysis (Appendix C); project management and review; technical lead, structured decision analysis
Charles Yaackulic	Ph.D., Ecology and Evolution; Research Statistician	Lead technical analyst humpback-chub trout modeling; subject matter expert, aquatic ecology, aquatic modeling

Name	Education/Experience	Contribution
U.S. Fish and Wildlife Service		
Sarah Rinkevich	Ecological Services/Federal Tribal Liaison.	Federal Tribal Liaison
Western Area Power Administration		
S. Clayton Palmer	M.A., Economics; 30 years experience in hydropower generation analysis, environmental economics, and economic and financial analysis	Contributing author of environmental justice section (Section 4.14) and lead author of electrical wholesale rate section (Appendix K.2); technical analyst and subject matter expert, hydropower modeling and power systems analysis
Thomas Hackett	B.S., Management/Computer Information Systems; 9 years experience in electricity rates and budget analyses.	Contributing author of electrical wholesale rate section (Appendix K.2); technical analyst hydropower modeling and power systems analysis

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8 GLOSSARY

A

Abiotic: Absence of living organisms, includes chemical and physical environments and processes.

Aboriginal: The first or earliest known of its kind present in a region.

Above mean sea level (AMSL): Elevation or altitude of any object relative to the average sea level.

Acre-foot: Volume of water, 43,560 cubic feet (ft³) (1,233 cubic meters [m³], 325,851 gallons), which would cover 1 acre to a depth of 1 foot.

Active capacity: Reservoir capacity normally available to store and regulate reservoir inflows to meet established reservoir operating requirements. For Lake Powell, this reservoir storage capacity is nearly 21 million acre-feet (maf).

Active conservation capacity: Reservoir capacity assigned to regulate reservoir inflow for irrigation, power generation, municipal and industrial use, fish and wildlife, navigation, recreation water quality, and other purposes. Also referred to as active storage. For Lake Powell, this is the reservoir storage above the penstock openings at an elevation of 3,490 feet (ft) (1,064 meters [m]).

Active storage: See active conservation capacity.

Adaptive management: Method or system for examining alternative strategies for meeting measurable goals and objectives and then, if necessary and in response to new information and/or changing circumstances, adjusting actions according to what is learned.

Adaptive Management Work Group (AMWG): Federal advisory committee to the Secretary of the Interior. Incorporates those stakeholders with interest in the operation of Glen Canyon Dam and downstream resources and continues public involvement in the decision-making process.

Advection: The typically horizontal movement of a mass of fluid, such as water.

Adverse impact: Abnormal, harmful, or undesirable effect that results from taking a particular action.

Aeolian processes: Erosion, transport, and deposition of sediment by the wind. Commonly occurs in areas with sparse or nonexistent vegetation, a supply of fine sediment, and strong winds.

Aerate: To supply or impregnate with gas, usually air.

1 Affected environment: Existing biological, physical, social, and economic conditions of an area
2 subject to change, both directly and indirectly, as the result of a proposed human action. Also,
3 the chapter in an environmental impact statement (EIS) describing current environmental
4 conditions. A description of the affected environment must include information necessary to
5 assess or understand impacts, must contain enough detail to support the impact analyses, and
6 must highlight environmentally sensitive resources.

7
8 Aggradation: Process of filling and raising the level of a streambed, floodplain, or sandbar by
9 deposition of sediment. The opposite of degradation.

10
11 Aggregation: A consistent and disjunct group of fish that has no significant exchange of
12 individuals with other aggregations, as indicated by recapture of tagged juveniles and adults and
13 movement of radio-tagged adults.

14
15 Air quality: Measure of the condition, including health-related and visual characteristics, of the
16 air. Often derived from quantitative measurements of the concentrations of specific injurious or
17 contaminating substances (i.e., air pollutants).

18
19 Air Quality Control Region (AQCR): An interstate or intrastate area designated by the
20 U.S. Environmental Protection Agency for the attainment and maintenance of National Ambient
21 Air Quality Standards.

22
23 Albedo (effects): The fraction of solar radiation reflected by a surface or object, often expressed
24 as a percentage. Snow-covered surfaces have a high albedo; the albedo of soils ranges from high
25 to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's albedo varies
26 mainly through varying cloudiness, snow, ice, leaf area, and land-cover changes.

27
28 Algae: Simple plants containing chlorophyll; most live submerged in water.

29
30 Algal bloom: Rapid and flourishing growth of algae.

31
32 Allocation, allotment: Refers to a distribution of water through which specific persons or legal
33 entities are assigned individual rights to consume pro-rata shares of a specific quantity of water
34 under legal entitlements. For example, a specific quantity of Colorado River water is distributed
35 for use within each Lower Division state through an apportionment. Water available for
36 consumptive use in that state is further distributed among water users in that state through the
37 allocation. An allocation does not establish an entitlement; the entitlement is normally
38 established by a written contract with the U.S. government.

39
40 Alluvial: Formed by the action of running water, such as that related to river and stream deposits.

41
42 Alluvium: Sedimentary material (e.g., clay, silt, sand, gravel, or other particulates) transported
43 and deposited by the action of flowing water.

44

- 1 Alternatives: Courses of action that may meet the specific goals and objectives of a proposed
2 action, often by different means and at varying levels of accomplishment, including the most
3 likely future conditions without the project (i.e., no action).
4
- 5 Ambient: Surrounding environment or natural conditions in a given place and time.
6
- 7 American Indian Tribe: Any extant or historical clan, Tribe, band, nation, or other group or
8 community of indigenous peoples in the United States.
9
- 10 American Indian Religious Freedom Act (P.L. 95-341) (AIRFA): Act requiring federal agencies
11 to consult with tribal officials to ensure protection of religious cultural rights and practices.
12
- 13 Amphibian: Cold-blooded, smooth-skinned vertebrate animal that has a life stage in water
14 (e.g., hatches as an aquatic larva with gills) and a life stage on land (e.g., transforms into an adult
15 with air-breathing lungs). Includes salamanders, frogs, and toads.
16
- 17 Amphipod: An order of crustacean that is found in almost all aquatic environments.
18
- 19 AMSL: See above mean sea level.
20
- 21 AMWG: See Adaptive Management Working Group
22
- 23 Anaerobic bacteria: Bacteria that survive and grow in environments with little or no oxygen.
24
- 25 Ancillary services: Those services necessary to support the transmission of electric power from
26 seller to purchaser given the obligations of control areas and transmitting utilities within those
27 control areas to maintain reliable operations of the interconnected transmission system. See
28 regulation and spinning reserves.
29
- 30 Anions: Ions that carry a negative charge (e.g., chloride, nitrate, sulfate, and phosphate).
31
- 32 Anoxic: Areas of water that are depleted of dissolved oxygen.
33
- 34 Antecedent: Prior or preceding event, condition, or cause.
35
- 36 Anthropogenic: Created, caused, or produced by humans.
37
- 38 Apportionment: Refers to the distribution of Colorado River water available to each Lower
39 Division state in normal, surplus, or shortage condition years, as set forth, respectively, in
40 Articles II(B)(1), II(B)(2), and II(B)(3) of the 1964 Supreme Court Decree in the case of Arizona
41 v. California.
42
- 43 Appropriation: Amount of water legally set apart or assigned to a particular purpose or use.
44
- 45 Aquatic: Living or growing in or on the water.
46

- 1 Aquatic biota: Collective term describing the organisms living in or depending on the aquatic
2 environment.
3
- 4 Aquatic habitat: Bodies of water that provide food, cover, and other elements critical to the
5 completion of an organism's life cycle (e.g., streams, rivers, and lakes).
6
- 7 Aquifer: Permeable water-bearing underground rock formation that readily yields usable
8 amounts of water to a well or spring. The formation could be sand, gravel, limestone, and/or
9 sandstone.
10
- 11 Archaeological and Historic Preservation Act (AHPA): Legislation that amended the Reservoir
12 Salvage Act of 1960, requiring federal agencies to provide for the preservation of historical and
13 archeological data that might otherwise be lost or destroyed as the result of any federally
14 licensed activity or program causing an alteration of terrain.
15
- 16 Archaeological resource: Any material remains or physical evidence of past human life or
17 activities that are of archeological interest, including the record of the effects of human activities
18 on the environment. An archeological resource is capable of revealing scientific or humanistic
19 information through archeological research.
20
- 21 Archaeological Resources Protection Act of 1979 (ARPA): Legislation establishing requirements
22 to protect archaeological resources and sites on public lands and Indian lands and to foster
23 increased cooperation and exchange of information between governmental authorities, the
24 professional archaeological community, and private individuals.
25
- 26 Archaeological site: A place (or group of physical sites) in which evidence of past activity is
27 preserved (either prehistoric or historic or contemporary); that has been, or may be, investigated
28 using the discipline of archaeology; and that represents a part of the archaeological record.
29
- 30 Archaic: In American archeology, a cultural stage following the earliest known human
31 occupation in the Americas (about 5500 BC to AD 100). This stage was characterized by a
32 hunting and gathering lifestyle and seasonal movement to take advantage of a variety of
33 resources.
34
- 35 Archaeology: Study of human cultures through the recovery and analysis of their material
36 remains.
37
- 38 Arid: A region that receives too little water to support agriculture without irrigation. Less than
39 10 in. of rainfall a year in a region is typically considered arid.
40
- 41 Arroyo: Gully or channel cut by an ephemeral stream.
42
- 43 Arthropod: Any of the invertebrate animals (such as insects, spiders, or crustaceans) having an
44 exoskeleton, a segmented body, and jointed limbs.
45
- 46 Artifact: Object produced or shaped by human beings and of archaeological or historical interest.

- 1 Aspect: The direction in which a feature faces.
2
- 3 Assemblage: A collection or community of plants or animals characteristically associated with a
4 particular environment, which can be used as an indicator of that environment.
5
- 6 Attainment Area: An area considered to have air quality as good as or better than the National
7 Ambient Air Quality Standards for a given pollutant. An area may be in attainment for one
8 pollutant and in nonattainment for others.
9
- 10 Attenuation: Gradual loss of strength or intensity.
11
- 12 Authorization: Act by the Congress of the United States that sanctions the use of public funds to
13 carry out a prescribed action.
14
- 15 Automatic generation control (AGC): Computerized power system regulation to maintain
16 scheduled generation within a prescribed area in response to changes in transmission system
17 operational characteristics.
18
- 19 Available hydropower (AHP): The monthly capacity and energy that is actually available based
20 on prevailing water release conditions.
21
- 22 Average peak annual discharge: Found by generating a list of the single highest value of
23 discharge from each year and calculating the mean.
24
- 25 **B**
26
- 27 Backwater: A relatively small, generally shallow area of a river with little or no current. See
28 return-current channel.
29
- 30 Bald and Golden Eagle Protection Act: Law passed in 1940 that prohibits anyone without a
31 permit issued by the Secretary of the Interior from taking bald or golden eagles, including their
32 parts, nests, or eggs.
33
- 34 Bank storage: Water absorbed and stored in the banks of a stream, lake, or reservoir, and
35 returned in whole or in part as the level of the water body surface falls.
36
- 37 Base flow: Portion of stream or river discharge that is derived from a natural storage source
38 (i.e., groundwater recharge).
39
- 40 Baseline: Information identified or found at the beginning of a study or experiment that serves as
41 a basis against which subsequent findings are measured or compared.
42
- 43 Baseload: Minimum load in a power system over a given period of time.
44

- 1 Baseload plant: Energy- or powerplant normally operated to produce the minimum amount of
2 power required to meet some or all of a given region's continuous energy demands.
3 Consequently, it operates essentially at a constant load.
4
- 5 Basin: Area of land that drains to a particular stream, river, pond, or lake.
6
- 7 Basin States: In accordance with the Colorado River Compact of 1922, the Colorado River Basin
8 is comprised of those parts of Arizona, California, Colorado, Nevada, New Mexico, Utah, and
9 Wyoming within and from which waters drain naturally into the Colorado River. These seven
10 states are referred to as the Basin States. See Colorado River Compact of 1922.
11
- 12 Bathymetric: Pertains to the study of the underwater depth of a lake, ocean, or reservoir floor.
13
- 14 Beach: Sandbar that generally is considered to have recreational value. See sandbar.
15
- 16 Bed elevation: Height of streambed above a specified level. Change in bed elevation in pools of
17 the Colorado River commonly is used as a measure of change in the amount of sediment stored
18 on the riverbed.
19
- 20 Bedload: Sediment moving on or near the streambed and frequently in contact with it.
21
- 22 Bed material: Unconsolidated material of which a streambed is composed.
23
- 24 Bedrock: Native consolidated, solid rock foundation underlying the surface. Above it is usually
25 an area of loose, broken, and weathered unconsolidated deposits of soil, sand, clay, or gravel.
26
- 27 Benthic: Living in or occurring at the bottom of a body of water.
28
- 29 Biodiversity: Number and kinds of organisms per unit area or volume; the composition of
30 species in a given area at the given time
31
- 32 Biological Assessment: Document prepared for the Endangered Species Act of 1973 (ESA)
33 Section 7 process to determine whether a proposed major construction activity under the
34 authority of a federal action agency is likely to adversely affect listed species, proposed species,
35 or designated critical habitat.
36
- 37 Biological control: The use of living organisms, such as predators, parasitoids, and pathogens, to
38 control pest insects, weeds, or diseases. Typically involves some human activity.
39
- 40 Biological Opinion (BO): Document stating the U.S. Fish and Wildlife Service (FWS) and the
41 National Marine Fisheries Service (NMFS) opinion as to whether a federal action is likely to
42 jeopardize the continued existence of a threatened or endangered species or result in the
43 destruction or adverse modification of critical habitat.
44
- 45 Biological response: Reactions or changes in cells, tissues, organs, and/or entire organisms
46 resulting from chemical, physical, or environmental agents and stressors.

1 Biomass: Total amount of combustible solid, liquid, or gas derived from biological processes
2 (e.g., living organisms) in a particular area or environment.

3
4 Biota: Living organisms (e.g., plants and animals) in a given region.

5
6 Blue-ribbon fishery: Designation made by the U.S. government and other authorities to identify
7 recreational fisheries of extremely high quality. The designation is typically based on water
8 quality, quantity, and accessibility; natural reproduction capacity; angling pressure; and the
9 specific species present.

10
11 Bryophytes: group of non-vascular, seedless plants including mosses, liverworts, and hornworts.

12
13 Bypass tube: Conduits that are used to release water in addition to the releases made through the
14 powerplant. See jet tube.

15
16 **C**

17
18 Campable area: Areas suitable for recreational camping.

19
20 Candidate species: Plant or animal species about which sufficient information is known on
21 biological status and threats to propose them as endangered or threatened. Undergoing status
22 review by the FWS, but not yet officially listed as threatened or endangered under the ESA.

23
24 Capacity: In power terminology, the load for which a generator, transmission line, or system is
25 rated; expressed in kilowatts. In this document, also refers to powerplant generation capability
26 under specific operating conditions and the amount of marketable resource under such
27 conditions.

28
29 Carbon dioxide (CO₂): A colorless, odorless, nonpoisonous gas that is a normal part of the
30 Earth's atmosphere. Carbon dioxide is a product of fossil fuel combustion, but is also exhaled by
31 humans and animals and absorbed by green growing things and by the sea. It is the most
32 prominent greenhouse gas that traps heat radiated into the atmosphere.

33
34 Carbon monoxide (CO): Colorless, odorless gas that is toxic if breathed in high concentrations
35 over an extended period. Listed as a criteria air pollutant under Title I of the Clean Air Act
36 (CAA).

37
38 Carnivore: Any flesh-eating or predatory organism.

39
40 Carrying capacity: Maximum density of wildlife or population of a specific species that a
41 particular region can sustain without deterioration of the habitat or hindering future generations'
42 ability to maintain the same population.

43
44 Catch and release: Practice within recreational fishing intended as a conservation measure in
45 which captured fish are unhooked and returned to the water before experiencing serious
46 exhaustion or injury.

- 1 Cations: Ions that carry a positive charge (e.g., sodium, magnesium, calcium, iron, and
2 aluminum).
3
- 4 Cenozoic age: Era about 1 to 1.5 million years ago.
5
- 6 Census block group: Geographic entities consisting of groups of individual census blocks.
7 Census blocks are grouped together so that they contain between 250 and 550 housing units.
8
- 9 Channel: Natural or artificial watercourse, with a definite bed and banks to confine and conduct
10 continuously or periodically flowing water.
11
- 12 Channel margin bar: Narrow sand deposits that continuously or discontinuously line the
13 riverbank.
14
- 15 Chemocline: Boundary or gradient between water masses of different chemical composition
16 (e.g., salinity).
17
- 18 Chironomid: Group of two-winged flying insects that live their larval stage underwater and
19 emerge to fly about as adults.
20
- 21 Cladocera: An order of small crustaceans commonly called water fleas.
22
- 23 Cladophora: Filamentous green alga that is very important to the food chain in the Colorado
24 River below Glen Canyon Dam.
25
- 26 Class I scenic resource: Classification of areas within Glen Canyon that have outstanding scenic
27 quality such as intricately carved landscapes, unique canyons, and unique geological features.
28
- 29 Class II scenic resource: Classification of an area within Glen Canyon that has superior quality
30 or a diversity of form and color.
31
- 32 Clay: Fine-grained soil, rock, or mineral fragment that has a diameter of less than
33 0.002 millimeters (mm). Clay is often made up of one or more minerals (e.g., hydrous aluminum
34 phyllosilicates, sometimes with iron, magnesium, alkali metals, alkaline earths, and other
35 cations) with traces of metal oxides and organic matter.
36
- 37 Clean Air Act (CAA): Comprehensive federal law that regulates air emissions. This act
38 establishes national ambient air quality standards (NAAQS) that protects public health and the
39 environment. Under this act, construction and operating permits, as well as reviews of new
40 stationary emissions sources and major modifications to existing sources, are required. It further
41 requires facilities to comply with emission limits or reduction limits stipulated in State
42 Implementation Plans (SIPs) and prohibits the federal government from approving actions that
43 do not conform to SIPs. Originally passed in 1963, the national air pollution control program is
44 actually based on the 1970 version of the law. The 1990 CAA Amendments, in large part, were
45 intended to deal with previously unaddressed or under-addressed problems such as acid rain,
46 ground level ozone, ozone depletion, and air toxics.

1 Clean Water Act (CWA): Establishes the basic structure for regulating discharges of pollutants
2 into the waters of the United States and regulating quality standards for surface waters. Under the
3 CWA, U.S. Environmental Protection Agency (EPA) has implemented several pollution control
4 programs, such as setting wastewater standards for industry and requiring National Pollutant
5 Discharge Elimination System (NPDES) permits for discharges of effluents to surface waters.
6 The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control
7 Act, but the Act was significantly reorganized and expanded in 1972. “Clean Water Act” became
8 the Act's common name with amendments in 1972.

9
10 Climate change: Significant and lasting change in the statistical distribution of weather
11 conditions and patterns over periods of years, ranging from decades to millions.

12
13 Clovis technological complex: A widespread, distinctive early Paleoindian culture defined by a
14 distinct form of fluted stone projectile points names for Clovis, New Mexico, the city near which
15 they were found. Clovis technology dates to around 13,500 years ago.

16
17 Cobble: Loose particles of rock or mineral (sediment) that range in size from 64 to 256 mm in
18 diameter. Cobbles are larger than gravel, but smaller than boulders.

19
20 *Code of Federal Regulations* (CFR): Codification and compilation of the general and permanent
21 rules published in the Federal Register by the departments and agencies of the United States
22 Federal Government. It is divided into 50 subject matter titles that represent broad areas subject
23 to federal regulation. Each title contains one or more individual volumes, which are updated once
24 each calendar year, on a staggered basis.

25
26 Cohort: A group of fish that were generated in the same spawning season and are born at the
27 same time.

28
29 Coldwater fish: Species of fish that require relatively cold water (50–60°F, or 10–15°C) to
30 survive. Cold water can hold more dissolved oxygen than warm water, so these species generally
31 inhabit deeper lakes and ponds in northern regions, spring-fed streams and lakes with a constant
32 cold water supply, or lakes in high altitudes that are cold. Rainbow trout is an example of a
33 coldwater species.

34
35 Colorado River Basin: All areas that drain to the Colorado River and its tributaries.

36
37 Colorado River Basin Project Act of 1968 (CRBPA): Act that authorized construction of a
38 number of water development projects, including the Central Arizona Project (CAP), and
39 required the Secretary of Interior to develop the Criteria for Coordinated Long-Range Operation
40 of Colorado River Reservoirs, or Long-Range Operating Criteria (LROC).

41
42 Colorado River Basin Salinity Control Act: Law enacted by Congress in 1974 that directed the
43 Secretary of the Interior to proceed with a program to enhance and protect the quality of water
44 available in the Colorado River for use in the United States and Republic of Mexico.

45

- 1 Colorado River Compact of 1922: Provides for the equitable division and apportionment of the
2 use of the waters of the Colorado River System between the Upper Basin and Lower Basin
3 states.
4
- 5 Colorado River Ecosystem: Community of aquatic, riparian, and terrestrial fauna and flora of the
6 Colorado River mainstream corridor and its tributaries, along with that system's processes and
7 environments. In general, the CRE encompasses the Colorado River primarily from the fore bay
8 of Glen Canyon Dam to the western boundary of Grand Canyon National Park and includes the
9 area where the Glen Canyon Dam operations impact physical, biological, recreational, cultural,
10 and other resources.
11
- 12 Colorado River Simulation System (CRSS): An operational model of the Colorado River Basin
13 based on a monthly time step.
14
- 15 Colorado River Storage Project Act (CRSPA) of 1956: Authorized comprehensive development
16 of the water resources of the Upper Basin states (Colorado, New Mexico, Utah, and Wyoming)
17 by providing for long-term regulatory storage of water, including construction of Glen Canyon
18 Dam, to meet the entitlements of the Lower Basin states (Arizona, California, and Nevada).
19
- 20 Commercial river trip: Trip organized by a boating company that conducts tours and recreational
21 outings for paying passengers.
22
- 23 Community: All members of a specified group of species present in a specific area at a specific
24 time; a group of people who see themselves as a unit.
25
- 26 Compact: Agreement between states apportioning the water of a river basin to each of the
27 signatory states.
28
- 29 Compact point: Lees Ferry, Arizona, the reference point designated by the Colorado River
30 Compact dividing the Colorado River into two sub-basins, the Upper Basin and the Lower Basin.
31
- 32 Concentration: Amount of a chemical in a particular volume or weight of air, water, soil, or other
33 medium.
34
- 35 Concrete-arch dam: Dam design often used in a narrow, steep-sided rock canyon with curvatures
36 in both horizontal and vertical directions. The safety of an arch dam is dependent on the strength
37 of the side wall abutments and the strength and elasticity of the concrete used in its construction.
38
- 39 Conductivity: Measure of the ability of water to pass an electrical current. Conductivity is an
40 indicator of the amount of dissolved salts in a stream, and is often used to estimate the amount of
41 total dissolved solids (TDS) rather than measuring each dissolved constituent separately.
42 Conductivity in water is also affected by temperature.
43
- 44 Confluence: Meeting point of two or more rivers.
45

- 1 Consolidated Decree: Entered by the United States Supreme Court on March 27, 2006, in the
2 case of *Arizona v. California*, 547 U.S. 150 (2006). In 1963, the Supreme Court reached a
3 Decision in the case of *Arizona v. California*. The 1964 Supreme Court Decree in the case of
4 *Arizona v. California* implemented the 1963 Decision. This 1964 Supreme Court Decree was
5 supplemented over time after its adoption and the Supreme Court entered a Consolidated Decree
6 in 2006 incorporating all applicable provisions of the earlier-issued Decisions and Decrees.
7
- 8 Consumptive water use: Total amount of water used by vegetation, human activities, and natural
9 cycling processes (e.g., evaporation, transpiration, incorporation) that is not available for other
10 uses within the system.
11
- 12 Continental climate: A climate lacking marine influence and characterized by more extreme
13 temperatures than marine climates; therefore, it has a relatively high annual temperature range
14 for its latitude.
15
- 16 Continental Divide: Drainage divide that separates the Atlantic and Pacific watersheds of North
17 America.
18
- 19 Contingent valuation: Survey method asking for the maximum values that users would pay for
20 access to a particular activity.
21
- 22 Control area: Part of a power system, or a combination of systems, to which a common electrical
23 generation control scheme is applied.
24
- 25 Convection: Motions in a fluid that result in the transport and mixing of the fluid's properties.
26
- 27 Cooperating Agency: With respect to the National Environmental Policy Act of 1969, as
28 amended, (NEPA) process, an agency that has jurisdiction by law or special expertise concerning
29 an aspect of a proposed federal action, and that is requested by the lead agency to participate in
30 the preparation of an Environmental Impact Statement.
31
- 32 Coordinated operation: Generally, the operation of two or more interconnected electrical systems
33 to achieve greater reliability and economy. As applied to hydropower resources, the operation of
34 a group of hydropower plants to obtain optimal power benefits with due consideration for all
35 other uses.
36
- 37 Copepods: Small crustaceans that live in virtually all marine and freshwater habitats.
38
- 39 Cosmology: Set of beliefs regarding the origin and structure of the universe.
40
- 41 Council on Environmental Quality (CEQ): Established by NEPA, CEQ regulations (40 CFR
42 Parts 1500–1508) describe the process for implementing NEPA, including preparation of EAs
43 and EISs, and the timing and extent of public participation.
44
- 45 Cover: Vegetation, rocks, or other materials used by wildlife for protection from predators
46 or weather.

- 1 Creel census: Angler survey to collect data on the harvest, size, and distribution of various
2 species of fish.
3
- 4 Criteria air pollutants: Six common air pollutants for which NAAQS have been established by
5 the U.S. EPA under Title I of the CAA. Included are sulfur dioxide (SO₂), nitrogen oxides
6 (NO_x), carbon monoxide (CO), ozone (O₃), particulate matter (PM_{2.5} and PM₁₀), and lead (Pb).
7 Standards were developed for these pollutants on the basis of scientific knowledge about their
8 health effects.
9
- 10 Critical habitat: Specific areas within the geographical area occupied by the species that have
11 physical or biological features essential to the conservation of a listed endangered or threatened
12 species and may require special management considerations or protection. These areas are
13 legally designated via Federal Register notices.
14
- 15 Cross-sectional area: Area of a stream, channel, or waterway, usually measured perpendicular to
16 the flow.
17
- 18 Crustacean: Aquatic animals with hard external skeletons and segmented limbs, belonging to the
19 class Crustacea; includes cladocerans, shrimp, crayfish, fairy shrimp, isopods, amphipods,
20 lobsters, and crabs.
21
- 22 Cubic foot per second (cfs): As a rate of streamflow, a cubic foot of water passing a reference
23 section in 1 second. A measure of a moving volume of water (1 cfs = 0.0283 m³/s).
24
- 25 Cultural modification: Any human-caused change in the land form, water form, or vegetation, or
26 the addition of a structure that creates a visual contrast in the basic elements (e.g., form, line,
27 color, or texture) of the naturalistic character of a landscape.
28
- 29 Cultural property: The tangible evidence or expression of cultural heritage such as works of art,
30 buildings, or their ruins.
31
- 32 Cultural resource: Any sites, districts, buildings, structures, objects, or features significant in
33 history, architecture, archeology, culture, or science. Also, Native American sacred sites or
34 special use areas that provide evidence of the prehistory and history of a community.
35
- 36 Cumulative impact: Impact assessed in an EIS that results from the incremental impacts of the
37 action when added to other past, present, and reasonably foreseeable future actions, regardless of
38 what agency (federal or nonfederal), private industry, or individual undertakes such other
39 actions. Cumulative impacts can result from individually minor but collectively significant
40 actions taking place over a period of time.
41
- 42 Cyanobacteria: Blue-green algae, prokaryotic, photosynthetic organisms that generally have a
43 blue-green tint and lack chloroplasts.
44
- 45 Cyprinids: Largest family of freshwater fish, commonly called the carp family or minnow
46 family.

1 **D**

2
3 Daily fluctuation: Difference between daily maximum and minimum releases from the dam.
4 These scheduled fluctuations are used to maximize efficiency of power generation.

5
6 Dead capacity: Reservoir capacity from which stored water cannot be evacuated by gravity. At
7 Glen Canyon Dam, this is the Lake Powell storage below the river outlet works openings at an
8 elevation of 3,374 ft (1,028 m).

9
10 Debris fan: Sloping mass of water and debris, including boulders, cobbles, gravel, sand, silt,
11 clay, and organic material (e.g., tree limbs), formed by debris flows at the mouth of a tributary.

12
13 Debris flow: Mixture of rocks, sediment, and organic material containing less than 40% water by
14 volume that flows downslope under the force of gravity (e.g., flash flood).

15
16 Defoliation: Process by which a plant, shrub, or tree loses its leaves. Possible causes include
17 insect activity, disease, chemicals, or the coming of autumn.

18
19 Degradation: Process wherein elevation of streambeds, floodplains, and sandbars is lowered by
20 erosion. The opposite of aggradation.

21
22 Delivery: The amount of water delivered to the point of use.

23
24 Delta: Flat alluvial area formed at the mouth of some rivers and streams (e.g., Colorado River)
25 where the mainstream flows into a body of standing water, such as a sea or lake (e.g., Lake
26 Powell or Lake Mead), and deposits large quantities of sediment.

27
28 Depletion: Loss of water from a stream, river, or basin resulting from consumptive use.

29
30 Deposition: Settlement of material out of the water column and on to the streambed or flooded
31 areas. Occurs when the energy of flowing water is unable to support the load of suspended
32 sediment.

33
34 Desiccation: Process of drying out.

35
36 Desired future condition (DFC): Measurable target or value, established for any resource area
37 that is of interest to managers; provides a reference point for evaluating treatment effectiveness
38 and the need to implement additional treatments or management actions.

39
40 Detritivore: An organism that feeds on dead and decomposing matter.

41
42 Detritus: Loose natural materials, such as rock fragments or organic particles, that result directly
43 from disintegration of rocks or organisms.

44
45 Diatom: Microscopic, single-celled, or colonial algae having cell walls of silica.

46

- 1 Diel fluctuations: Changes or fluctuations that occur in a 24-hour period that usually includes a
2 day and the adjoining night.
3
- 4 Diptera: Order of insects that includes all true flies.
5
- 6 Direct effect (impact): Effect on the environment caused by an action; occur at the same time and
7 place as the initial action.
8
- 9 Discharge (flow): Volume of water that is released from the dam at any given time or that passes
10 a given point within a given period of time. Usually expressed in cubic feet per second (cfs).
11
- 12 Dispatch: The operating control of an integrated electric system whose job it is to (1) assign
13 generation to specific generating plants and other sources of electric supply to effect the most
14 reliable and economical supply as the total of the significant area loads rises or falls; (2) control
15 operations and maintenance of high-voltage lines, substations, and equipment, including
16 administration of safety procedures; (3) operate the interconnection; and (4) schedule energy
17 transactions with other interconnected electric utilities.
18
- 19 Dissolved oxygen (DO): Amount of free oxygen found in water expressed as a concentration,
20 milligrams per liter (mg/L), or as percent saturation (the amount of oxygen the water holds
21 compared to the maximum amount it could absorb at that temperature). Low DO levels adversely
22 affect fish and other aquatic life. The ideal dissolved oxygen for fish life is between 7 and
23 9 mg/L; most fish cannot survive when DO falls below 3 mg/L.
24
- 25 Dissolved solids: See total dissolved solids (TDS).
26
- 27 Divert: To direct a flow away from its natural course.
28
- 29 Downstream: Situated or moving in the direction of a stream or river's current.
30
- 31 Drainage: Process of removing surface or subsurface water from a soil or area.
32
- 33 Drawdown: Lowering of a reservoir's water level; process of depleting reservoir or groundwater
34 storage.
35
- 36 Drift: Food organisms dislodged and moved by river current. Can include algae, plankton,
37 invertebrates, and larval fish.
38
- 39 Driftwood: Remains of trees that have been washed onto a shoreline by the action of winds,
40 tides, or waves.
41
- 42 Drought: Period of unusually persistent dry weather that persists long enough to cause serious
43 problems such as crop damage and/or water supply shortages.
44
- 45 Dune: Wind-deposited sand body, usually a rounded hill, ridge, or mound.
46

1 **E**

2
3 Ecological resource: Animals, plants, and the habitats in which they live, which may be land, air,
4 or water.

5
6 Ecological restoration: Process of assisting in the recovery of an ecosystem that has been
7 degraded, damaged, or destroyed.

8
9 Ecology: The relationship between living organisms and their environments.

10
11 Ecoregion: A geographically distinct area of land that is characterized by a distinctive climate,
12 ecological features, and plant and animal communities.

13
14 Ecosystem: Complex system composed of a community of fauna and flora and that system's
15 chemical and physical processes and environment.

16
17 Ecosystem management: Approach to natural resource management that seeks an understanding
18 of the interrelationships among important physical, chemical, biological, cultural, political, and
19 social processes in order to conserve resources and sustain ecosystems to meet both ecological
20 and human needs of current and future generations.

21
22 Ectoparasitic: Living on the exterior of another organism, the host, obtaining nourishment from
23 the latter.

24
25 Eddy: Current of water moving against the main current in a circular pattern. See recirculation
26 zone.

27
28 Effect: Environmental consequences (the scientific and analytical basis for comparison of
29 alternatives) that occur as a result of a proposed action. See direct effect and indirect effect.

30
31 Efficiency: Ratio of useful energy output to total energy input, usually expressed as a percentage.

32
33 Electric power system: Physically connected electric power generating, transmission, and
34 distribution facilities operated as a unit under one control.

35
36 Electrical demand: Energy requirement placed upon a utility's generation at a given instant or
37 averaged over any designated period of time.

38
39 Electrofishing: Application of a direct electric current to attract and temporarily immobilize fish
40 for easy capture. See mechanical removal.

41
42 Embayment: a recess or an indentation in a shore line that forms an area with low flow.

43
44 Emergent marsh plants: Plants that are rooted in soil with basal portions that typically grow
45 beneath the surface of the water but whose leaves, stems, and reproductive organs are above the
46 water.

- 1 Emissions: Substances that are discharged into the air from industrial processes, vehicles, and
2 living organisms.
3
- 4 Empirical: Based on experimental data rather than theory.
5
- 6 Encroachment: Act of advancing, intruding, or extending beyond established, usual, or proper
7 limits.
8
- 9 Endangered species: Species or subspecies (plant or animal) whose survival is at risk of
10 extinction throughout all or a significant portion of its range because it is either few in numbers
11 or threatened by changing environmental or predation parameters. Requirements for declaring a
12 species endangered are found in the ESA.
13
- 14 Endangered Species Act of 1973 (ESA): Provides a federal program for the conservation of
15 threatened and endangered plants and animals and the habitats in which they are found. Requires
16 consultation with the FWS and/or the National Oceanic and Atmospheric Administration
17 (NOAA) Fisheries Service to determine whether endangered or threatened species or their
18 habitats will be affected by a proposed activity and what, if any, mitigation measures are needed
19 to address the impacts.
20
- 21 Endemic: Native to and restricted to a particular geographic region.
22
- 23 Energy: Electric capacity generated and/or delivered over time; usually measured in kilowatt-
24 hours.
25
- 26 Environmental Assessment (EA): Concise public document that a federal agency prepares under
27 NEPA to provide sufficient evidence and analysis to determine whether a proposed action, or its
28 alternatives, may have significant environmental effects on the human environment. In general,
29 an EA must include brief discussions on the need for the proposal, the alternatives, the
30 environmental impacts of the proposed action and alternatives, and a list of agencies and persons
31 consulted. If significant effects may occur, an EIS is prepared instead of an EA.
32
- 33 Environmental Impact Statement (EIS): Detailed document required of federal agencies under
34 NEPA for major proposals or legislation that will or could significantly affect the environment.
35 An EIS is prepared with public participation and must disclose significant issues and impacts on
36 the human environment that may result from the proposed action or its alternatives. An EIS
37 includes the following: the environmental impact of the proposed action; any adverse impacts
38 that cannot be avoided by the proposed action; alternative courses of action; relationships
39 between local short-term use of the human environment and the maintenance and enhancement
40 of long-term productivity; and a description of the irreversible and irretrievable commitment of
41 resources that would occur if the action were accomplished.
42
- 43 Environmental justice: Fair treatment of people of all races, cultures, incomes, and educational
44 levels with respect to the development, implementation, and enforcement of environmental laws,
45 regulations, and policies.
46

- 1 Ephemeral stream: Stream that flows briefly only in direct response to precipitation and whose
2 channel is, at all times, above the water table.
3
- 4 Epilimnion: Top layer of a thermally stratified lake or reservoir that exhibits essentially uniform
5 warmer temperature. See stratification.
6
- 7 Epiphyte: A plant that derives its moisture and nutrients from the air and rain and grows on
8 another plant for support.
9
- 10 Equalization flow: Dam releases made to balance water storage between Lake Powell and Lake
11 Mead. Pursuant to the Interim Guidelines, these flow events are carried out if (1) the end of the
12 water year storage forecast for Lake Powell is greater than that of Lake Mead; and (2) the storage
13 forecast for the end of the water year in the Upper Basin reservoirs is greater than the quantity of
14 storage required by Section 602(a) of the CRBPA (602[a] storage) for that same date.
15
- 16 Equalization tier: Operation elevation that applies when Lake Powell's projected January 1
17 elevation is above the elevation in the equalization table of the Interim Guidelines (Table 2.3-1
18 of DOI 2007). The tier provides for Lake Powell releases of more than 8.23 maf during the water
19 year until the content of the lakes equalizes or certain elevations are attained.
20
- 21 Erosion: Gradual destruction or wearing away of a material (e.g., rock or sand) or object
22 (e.g., beach) by water, wind, or other natural agents.
23
- 24 Ethnobotany (ethnobotanical): The plant lore and agricultural customs of a people; the study of
25 such lore and customs.
26
- 27 Ethnohistory: The use of both historical and ethnographic data such as maps, music, paintings,
28 photography, folklore, and oral tradition to understand a culture on its own terms and according
29 to its own cultural code.
30
- 31 Euphotic zone: The superficial layer of a water body within the range of effective light
32 penetration for photosynthesis.
33
- 34 Eutrophication: Enrichment of a body of water as a result of high concentrations of minerals and
35 organic nutrients (especially nitrogen and phosphorus) that stimulate and promote the
36 proliferation of aquatic plant life, thus reducing the dissolved oxygen content of the water.
37
- 38 Evaporation: Water vapor losses to the atmosphere from land areas, bodies of water, and all
39 other moist surfaces.
40
- 41 Evapotranspiration: Sum of water transpired or used by plants and evaporated from surfaces
42 (e.g., water bodies and soils) in a specific time period; usually expressed in depth of water per
43 unit area.
44

- 1 Exceedance: Measured level of an air pollutant that is higher than the national or state ambient
2 air quality standards. Also applies to water volume, flow, or energy generation that is above a
3 particular percentage (exceedance level).
4
- 5 Excess capacity: Power generation capacity available on a short-term basis in excess of the firm
6 capacity available through long-term contracts.
7
- 8 Executive Order (EO): President’s or governor’s directive or declaration that implements or
9 interprets a federal statute, a constitutional provision, or a treaty. It has the force of law and is
10 usually based on existing statutory powers; requires no action by Congress or a state legislature.
11
- 12 Existence value: Value people place on simply knowing an area or feature continues to exist in a
13 particular condition.
14
- 15 Exotic species: Nonnative plant or animal deliberately or accidentally introduced into a new
16 habitat where it is able to reproduce and survive.
17
- 18 Experimental flow: Investigational releases (e.g., high-flow experiments) that are designed to
19 explore, test, and assess the relationships between dam operations and downstream resources in
20 and along the Colorado River within the Grand Canyon National Park (GCNP) and Glen Canyon
21 National Recreation Area (GCNRA).
22
- 23 Experimental population: Specific reintroduced populations of listed species under the ESA. The
24 FWS determines whether an experimental population is “essential” or “nonessential” to the
25 continued existence of the species.
26
- 27 Exposure: Contact of an organism with a chemical, radiological, or physical agent.
28
- 29 Extinct species: Species having no living members, such that it is no longer in existence.
30
- 31 Extirpated species: Species that no longer exists in a given region or area.
32
- 33 Extirpation: Elimination of a species or subspecies from a particular area, but not from its entire
34 range.
35
- 36 **F**
37
- 38 Fan-eddy complex: An assemblage of geomorphic features created by a debris fan that projects
39 into a stream or river and creates an area of recirculation (eddy) just downstream of the debris
40 fan.
41
- 42 Fauna: Animals in a specific region or habitat, considered as a group.
43
- 44 Feature: Large, complex artifact, or part of a site, such as a hearth, cairn, housepit, rock
45 alignment, or activity area.
46

- 1 Fecal coliform bacteria: Group of organisms common to the intestinal tracts of humans and
2 animals. The presence of fecal coliform bacteria in water is an indicator of pollution and of
3 potentially dangerous bacterial contamination.
4
- 5 Fecundity: Number of produced eggs or offspring; reproductive capability.
6
- 7 *Federal Register*: Official daily publication for rules, proposed rules, and notices of federal
8 agencies and organizations, as well as executive orders and other presidential documents;
9 published by the Office of the Federal Register, National Archives and Records Administration
10 (NARA).
11
- 12 Filamentous algae: Plant that forms a greenish mat on the water surface.
13
- 14 Finding of No Significant Impact (FONSI): NEPA document issued by a federal agency briefly
15 presenting the reasons why an action, not otherwise excluded, will not have a significant effect
16 on the human environment if implemented. This finding is based on the results of an EA and
17 other factors in the public planning record for a proposed action.
18
- 19 Fine sediment: Soil particles, typically defined as less than 1–2 mm in diameter (e.g., clay and
20 silt), that are naturally filtered from coarser fractions and carried by water.
21
- 22 Firm energy or power: Uninterruptible energy and power guaranteed by the supplier to be
23 available at all times except for reasons of uncontrollable forces or continuity of service
24 provisions.
25
- 26 Fishery: Specified waters or area where fish or other aquatic animals are reared and caught.
27
- 28 Flash flood: Sudden high-flow event through a valley, canyon, or wash, following a short
29 duration, high-intensity rainfall.
30
- 31 Flatwater boating: Form of low-speed boating (e.g., canoeing or kayaking) that relies on flat
32 waters (e.g., lakes, gorges, or slow-moving rivers), as opposed to rapids or white water.
33
- 34 Flood: Relatively high flow or inundation of water, as measured by either gage height or
35 discharge quantity, that overtops the natural or artificial banks in any reach of a river and
36 threatens or causes damage.
37
- 38 Flood Control Act of 1944: Act authorizing the construction of certain public works on rivers
39 and harbors for flood control and other purposes.
40
- 41 Flood control capacity: Reservoir capacity assigned for the sole purpose of regulating flood
42 inflows to reduce flood damage downstream.
43
- 44 Flood control pool: Reservoir volume above the active conservation and joint-use pool that is
45 reserved for flood runoff and then evacuated as soon as possible to keep that space in readiness
46 for the next flood. See reservoir capacity.

- 1 Flood flows: In this report, water releases from Glen Canyon Dam in excess of powerplant
2 capacity (i.e., 31,500 cfs).
3
- 4 Floodplain: Mostly level, low-lying land adjacent to a water body that is subjected to inundation
5 and submersion during high flow or rainfall events. The relative elevations of floodplain areas
6 determine their frequency of flooding, which ranges from rare, severe, storm events to flows
7 experienced several times a year.
8
- 9 Flora: Community of plants in a specific region or habitat, considered as a group.
10
- 11 Flow: Volume of water passing a given point per unit of time. See instream flow requirements,
12 minimum flow, peak flow, ponding flow, return flow, spike flow, and steady flow.
13
- 14 Flow regime: Flow variation through time resulting from operations of the Glen Canyon Dam.
15
- 16 Fluctuating flows: Water released from Glen Canyon Dam that varies in volume, usually within
17 a given range (e.g., 1,000 to 31,500 cfs), over a 24-hour period.
18
- 19 Fluctuation zone: Area of a sandbar or vegetation zone that is within the range of fluctuating
20 flow.
21
- 22 Fluvial: Pertaining to a river or stream; indicates the presence or interaction of a river within an
23 area or landform.
24
- 25 Fluvial geomorphology: Study and examination of stream and river channels, including the
26 processes that operate in river systems and the landforms which they create or have created, both
27 in their natural setting as well as how they respond to human-induced changes in a watershed.
28
- 29 Folsom technological complex: A widespread, distinctive early Paleoindian culture defined by a
30 distinct form of fluted stone projectile points named for Folsom, New Mexico, the city near
31 which they were found. Folsom technology dates to between 11,500 and 10,000 years ago.
32
- 33 FONSI: See Finding of No Significant Impact.
34
- 35 Food chain: Succession of organisms in a community in which food energy is transferred from
36 one organism to another as each consumes a lower member and in turn is consumed by a higher
37 member.
38
- 39 Food web: Complex system or network of interrelated and interdependent food chains that
40 describes how food energy is passed throughout an ecological community.
41
- 42 Food base: Substances or materials that provide living things with the nutrients they need to
43 provide energy, grow, and sustain overall life.
44
- 45 Forage fish: Generally, small fish that produce prolifically and are consumed by predators.
46

- 1 Forced outage: Nonscheduled shutting down of a generating unit or other facility for emergency
2 or other unforeseen reasons.
3
- 4 Forebay: Impoundment immediately above a dam or hydroelectric powerplant intake structure.
5
- 6 Fossil fuel: An energy source formed in the Earth's crust from decayed organic material.
7 Common fossil fuels are petroleum, coal, and natural gas.
8
- 9 Fragmentation: Process by which habitats are increasingly subdivided into smaller units,
10 resulting in their increased insularity as well as losses of total habitat area.
11
- 12 Fry: Life stage of fish between the egg and fingerling stages.
13
- 14 Fugitive dust: The dust released from any source other than a definable point source such as a
15 stack, chimney, or vent. Sources include construction activities, storage piles, and roadways.
16
- 17 Full pool: Volume of water in a reservoir at maximum design elevation. At Lake Powell this is at
18 an elevation of 3,700 ft (1,130 m). Total volume is 27 maf; this volume is decreasing as the lake
19 fills with sediment.
20
- 21 **G**
22
- 23 Gage: Device or instrument used for measuring or testing.
24
- 25 Gated spillway: Overflow section of dam restricted by use of gates that can be operated to
26 control releases from the reservoir to ensure the safety of the dam.
27
- 28 Gaging station: Specific location on a river or stream where systematic observations and
29 measurements of hydrologic data are obtained through mechanical or electrical means.
30
- 31 Generation (power): Process of producing electrical energy by transforming other forms of
32 energy. Also, the amount of electric energy produced.
33
- 34 Generator: Machine that converts mechanical energy into electrical energy.
35
- 36 Geology: Science that deals with the study of the materials, processes, environments, and history
37 of the Earth, including rocks and their formation and structure.
38
- 39 Geomorphology: Geological study of the configuration and evolution of land forms and earth
40 features.
41
- 42 Gigawatt-hour (GWh): One billion watt-hours of electrical energy.
43
- 44 Glen Canyon Dam: Second highest concrete arch dam in the United States. Constructed to
45 harness the power of the Colorado River to provide for the water and power needs for people in
46 the western United States.

1 Glen Canyon Dam Adaptive Management Program (GCDAMP): Provides an organization and
2 process for cooperative integration of dam operations, downstream resource protection and
3 management, and monitoring and research information, as well as to improve the values for
4 which the GCNP and GCNRA were established.

5
6 Glen Canyon Environmental Studies (GCES): Program started by Bureau of Reclamation in
7 1982 to collect scientific evidence on the positive and negative impacts on downstream
8 environmental and cultural resources as a result of daily fluctuating releases from the dam.

9
10 Glen Canyon National Recreation Area (GCNRA): Area that encompasses hundreds of square
11 miles from Lees Ferry in Arizona to the Orange Cliffs of southern Utah for water-based and
12 backcountry recreation.

13
14 Global warming: Increase in the near-surface temperature of the Earth. Global warming has
15 occurred in the distant past as the result of natural influences, but the term is today most often
16 used to refer to the warming that many scientists predict will occur as a result of increased
17 anthropogenic emissions of greenhouse gases.

18
19 Gradient: See slope.

20
21 Grand Canyon Monitoring and Research Center (GCMRC): Science provider for the GCDAMP.
22 Operated by the U.S. Geological Survey, the GCMRC provides relevant scientific information
23 about the status and trends of natural, cultural, and recreational resources found in those portions
24 of the GCNP and GCNRA affected by Glen Canyon Dam operations.

25
26 Grand Canyon National Park (GCNP): A National Park since 1919, the area contains unique
27 combinations of erosional forms. It is 277 river miles long and up to 18 miles wide. The area
28 encompasses 1,218,375 acres and lies on the Colorado Plateau in northwestern Arizona, with
29 land that is semiarid and consists of raised plateaus and structural basins.

30
31 Grand Canyon National Park Enlargement Act: An act of Congress enacted in 1975 to further
32 protect the Grand Canyon by enlarging the park in the state of Arizona.

33
34 Grand Canyon Protection Act of 1992 (GCPA): Directs the operation of Glen Canyon Dam in
35 compliance with existing law to protect, mitigate adverse impacts on, and improve the values for
36 which the GCNP and GCNRA were established, including, but not limited to, natural and
37 cultural resources and visitor use.

38
39 Green algae: Members of the plant phylum Chlorophyta, which possess the green pigment
40 chlorophyll that they use to capture light energy to fuel the manufacture of sugars. This diverse
41 group of algae are primarily freshwater eukaryotic organisms, which serve as food and oxygen
42 sources for other aquatic organisms.

43

1 Greenhouse effect: Increasing mean global surface temperature of the Earth caused by gases in
2 the atmosphere (including carbon dioxide, methane, nitrous oxide, ozone, and
3 chlorofluorocarbon). The greenhouse effect allows solar radiation to penetrate, but also absorbs
4 infrared radiation returning to space.

5
6 Greenhouse gases (GHGs): Heat-trapping gases in the atmosphere that contribute to global
7 warming and temperature gain near the Earth's surface. Natural and human-made GHGs include
8 water vapor, carbon dioxide, methane, nitrogen oxides, ozone, and fluorinated gases
9 (e.g., chlorofluorocarbons).

10
11 Gross generation: Total amount of electrical energy produced by a generating station or stations,
12 measured at generator terminals.

13
14 Groundwater: Supply of water found beneath the Earth's surface, usually in porous rock
15 formations (i.e., aquifers), which may supply wells and springs.

16
17 Gully: Landform that erodes sharply into soil, typically on a hillside; caused by running water.
18 Gullies are similar to ditches or small valleys, but they are typically only 3 to 30 ft (0.9 to 9 m)
19 wide and deep.

20
21 **H**

22
23 Habitat: Area or place, including physical and biotic conditions, where a plant or animal lives.

24
25 Hanging garden: Unique biological feature formed when spring water flows through cracks in
26 the sandstone and seeps out through the canyon walls and allows plants to grow vertically.

27
28 Harvest: In a recreational fishery, refers to numbers of fish that are caught and kept.

29
30 Head: Height of water above a specified point.

31
32 Headwater: Source and upper part of a stream or lake inflow.

33
34 Heavy metal: Metallic elements with high atomic weights (e.g., lead, mercury, cadmium,
35 chromium, and arsenic) that are generally toxic in relatively low concentrations to plant and
36 animal life.

37
38 Herbaceous: The plant strata that contain soft, not woody, stemmed plants that die to the ground
39 in winter.

40
41 Herbivore: Animal that feeds on plants.

42
43 Herpetofauna: General grouping for reptiles and amphibians.

44

- 1 High flow: Pulses or temporary influxes of water that typically occur after periods of
2 precipitation and are contained within the natural banks of the river (i.e., do not cause flooding).
3 In a river, these events can lead to a temporary reduction in downstream temperature and
4 increase in salinity, dissolved oxygen, and turbidity. High flows suspend and deliver large
5 amounts of sediment and organic matter downstream, which can redeposit on sandbars and
6 beaches. They can also restore and enhance riparian vegetation and can prevent undesirable
7 vegetation from invading river channels. In addition, high-flow events can work to reshape and
8 maintain native fish habitats, stimulate food base production, and suppress numbers of nonnative
9 fish.
- 10
- 11 High-flow experiment (HFE): High-volume test releases (31,500 to 45,000 cfs) from the
12 Glen Canyon Dam that are performed under sediment-enriched conditions. HFEs are specifically
13 designed to benefit downstream resources; this includes maintaining and rebuilding sandbars and
14 beaches in downstream reaches. Also referred to as a high-flow test.
- 15
- 16 High-flow test: See high-flow experiment.
- 17
- 18 Historic: The time period after the appearance of written records. In the New World, this
19 generally refers to the time period after the beginning of European settlement at approximately
20 1600 A.D.
- 21
- 22 Historic property: Any prehistoric or historic district, site, building, structure, or object included
23 in, or eligible for inclusion in, the *National Register of Historic Places* maintained by the
24 Secretary of the Interior. They include artifacts, records, and remains that are related to and
25 located within such properties.
- 26
- 27 Historic resource: In the United States, material remains and the landscape alterations that have
28 occurred since the arrival of Europeans.
- 29
- 30 Human environment: Natural and physical environment and the relationship of people with that
31 environment including all combinations of physical, biological, cultural, social, and economic
32 factors in a given area.
- 33
- 34 Hydraulic: Powered by water.
- 35
- 36 Hydroelectric plant: Electric powerplant using falling water as its motive force.
- 37
- 38 Hydroelectric power: Electricity produced by water.
- 39
- 40 Hydrogen sulfide (H₂S): A colorless, flammable, and extremely hazardous gas that occurs
41 naturally in crude petroleum, natural gas, and hot springs.
- 42
- 43 Hydrograph: Graph showing, for a given point in a stream, the discharge, stage, velocity, or other
44 property of water with respect to time.
- 45

- 1 Hydrologic budget: An accounting of the inflow to, outflow from, and storage change in a
2 hydrologic unit such as an aquifer or drainage basin.
3
- 4 Hydrologic cycle: Continuous circulation of water in all of its phases (gas, liquid, solid) from the
5 atmosphere to Earth by precipitation, and from Earth to the atmosphere by evaporation and
6 transpiration. The land phase includes infiltration, runoff, and exchange between surface water
7 and ground water.
8
- 9 Hydrology: Science dealing with the occurrence, properties, distribution, circulation, and
10 transport of water, including groundwater, surface water, rain, and snow.
11
- 12 Hydropower: See hydroelectric power.
13
- 14 Hypolimnetic: Pertaining to the lower, colder portion of a lake or reservoir, which is separated
15 from the upper, warmer portion (epilimnion) by the thermocline.
16
- 17 Hypolimnion: Non-circulating bottom layer of a thermally stratified lake or reservoir that
18 exhibits essentially uniform colder temperature and low dissolved oxygen.
19
- 20 Hypoxia: depressed levels of dissolved oxygen in water, usually resulting in decreased
21 metabolism.
22
- 23 **I**
24
- 25 Igneous rock: A crystalline rock formed by the cooling and solidification of molten or partly
26 molten material (magma). Igneous rock includes volcanic rock (rock solidified above the Earth's
27 surface) and plutonic rock (rock solidified at considerable depth).
28
- 29 Impact: Effect, influence, alteration, or imprint caused by an action. See adverse impact,
30 cumulative impact, direct impact, and indirect impact.
31
- 32 Impoundment: Body of water created by a dam, dike, floodgate, or other barrier.
33
- 34 Inactive capacity: Reservoir capacity that can be released from the dam but is normally not
35 available (i.e., for power generation) because of operating agreements or physical restrictions. At
36 Glen Canyon Dam, this is the reservoir storage above the river outlet works openings at elevation
37 3,374 ft (1,038 m) and below the penstock openings at elevation 3,490 ft (1,064 m), which is
38 about 3.9 maf.
39
- 40 Indian trust assets: Lands, natural resources, or other assets held in trust or restricted against
41 alienation by the United States for Native American Tribes or individual Native Americans.
42
- 43 Indian trust resource: Those natural resources, either on or off Indian lands, retained by or
44 reserved by or for Indian Tribes through treaties, statutes, judicial decisions, and Executive
45 Orders, which are protected by a fiduciary obligation on the part of the United States.
46

- 1 Indigenous: Native to an area.
2
- 3 Indirect effect (impact): Effect that occurs away from the place of action with effects that are
4 related to, but removed from, a proposed action by an intermediate step or process. An example
5 would be changes in surface-water quality resulting from soil erosion at construction sites.
6
- 7 Inflow: Amount or rate of water flowing into a body of water. In this report, the water flowing
8 into Lake Powell from the Colorado River and/or its tributaries; or water entering the Colorado
9 River from tributaries between Glen Canyon Dam and Lake Mead; or water flowing into Lake
10 Mead, mainly from the Colorado River.
11
- 12 Infrastructure: Basic facilities, utilities, services, and transportation framework needed to meet
13 public and administrative needs for the functioning of an organization, system, or community.
14
- 15 In-situ: In its natural position or place; unmoved, unexcavated, remaining at the site or
16 subsurface.
17
- 18 Insolation: Solar energy that is received on a given surface area during a given time.
19
- 20 Instream flow requirements: Amount of water flowing through a stream course needed to sustain
21 instream values.
22
- 23 Intake: Structure in a dam, reservoir, or river through which water can be drawn into an outlet
24 pipe or waterway.
25
- 26 Interconnected systems: System consisting of two or more individual power systems normally
27 operating with connecting tie lines.
28
- 29 Interflow: Lateral movement of water in the upper layer of soil.
30
- 31 Interim shortage criteria/interim guidelines: Operational guidelines and coordinated reservoir
32 management strategies (established in 2007) to address operations of Lake Powell and Lake
33 Mead, particularly under drought and other low reservoir conditions. These criteria also provide
34 a greater degree of certainty to U.S. Colorado River water users and managers of the Colorado
35 River Basin by detailing information on when, and by how much, water deliveries will be
36 reduced under specified reservoir conditions.
37
- 38 Intermittent stream: Stream that flows only at certain times of the year when the ground-water
39 table is high; occasionally is dry or reduced to a pool stage when losses from evaporation or
40 seepage exceed the amount of inflow.
41
- 42 Inundate: To cover with impounded waters or floodwaters.
43
- 44 Invasive species: Nonnative plant or animal, including noxious and exotic species, that is an
45 aggressive colonizer and can out-compete other species. Their introduction causes or is likely to
46 cause economic or environmental harm or harm to human health.

1 Invertebrate: Animal without a spinal cord, usually replaced by a hard exoskeleton or shell.
2 Examples include insects, spiders, crayfish, snails, or clams.

3

4 Ion: Atom or molecule that carries either a positive or negative electrical charge.

5

6 Irretrievable commitments of resources: Those resources that are lost or lose value for a period
7 of time and cannot be restored as a result of an action, such as temporary loss of power
8 productivity due to of modified operations.

9

10 Irreversible commitments of resources: Those resources that cannot be regained, restored, or
11 returned to their original condition within a reasonable time frame, such as the extinction of a
12 species.

13

14 Irrigation district: A cooperative, self-governing public corporation set up as a subdivision of the
15 state government, with definite geographic boundaries; organized and having taxing power to
16 obtain and distribute water for irrigation of lands within the district; created under the authority
17 of a State legislature with the consent of a designated fraction of the landowners or citizens.

18

19 **J**

20

21 Jeopardy opinion: FWS or NMFS opinion that an action is likely to jeopardize the continued
22 existence of a listed species or result in the destruction or adverse modification of critical habitat.

23

24 Jet tube: A Glen Canyon Dam outlet that releases water below the level of penstocks. Four jet
25 tubes with a combined release capacity of 15,000 cfs, are not equipped with generation
26 capability, but allow for a total release of about 45,000 cfs when used in combination with
27 maximum releases from each of the 8 penstocks.

28

29 Juvenile: Young organism older than 1 year but not having reached reproductive age.

30

31 **K**

32

33 Kaibab formation: The rock that makes the canyon rims and is the youngest of the
34 Grand Canyon's geologic layers.

35

36 Kilovolt (kV): 1,000 volts (V).

37

38 Kilowatt (kW): Unit of electric power capacity equal to 1,000 watts (W), or about
39 1.34 horsepower (HP).

40

41 Kilowatt-hour (kWh): Basic unit of electric energy equaling an average of one kilowatt of power
42 applied over one hour.

43

1 **L**

2

3 Lake Mead National Recreation Area (LMNRA): American's first national recreation area;
4 encompasses Lake Mead and Lake Mohave.

5

6 Lake Powell: Reservoir created by the completion of the Glen Canyon Dam on the
7 Colorado River in 1963.

8

9 Landform: Any feature of the Earth's surface having a distinct shape and origin. Landforms
10 include major features (such as continents, ocean basins, plains, plateaus, and mountain ranges)
11 and minor features (such as hills, valleys, slopes, drumlins, and dunes).

12

13 Landmark (historic): Significant historic places designated by the Secretary of the Interior
14 because they possess exceptional value or quality in illustrating or interpreting the heritage of the
15 United States.

16

17 Landmark (visual): Type of reference point external to the observer. Usually a simply defined
18 physical object that can be seen from many angles and distances over the tops of smaller
19 elements and used as a radial reference.

20

21 Landscape: Traits, patterns, and structure of a specific geographic area including its biological
22 composition, its physical environment, and its anthropogenic or social patterns.

23

24 Larva, larvae (pl.): The immature stage between the egg and pupa of insects having complete
25 metamorphosis where the immature differs radically from the adult (e.g., caterpillars, grubs).

26

27 Larval fish: First life stage of fish after hatching. Larvae are not able to feed themselves, and
28 carry a yolk-sac that provides their nutrition.

29

30 Latitude: Angular distance north or south of the equator, measured in degrees.

31

32 Law of the River: As applied to the Colorado River, the collective set of documents that
33 apportions the Colorado River waters and regulates the use and management of the
34 Colorado River among the seven Basin States and Mexico. It is comprised of numerous
35 operating criteria, regulations, and administrative decisions included in federal and state statutes,
36 interstate compacts, court decisions and decrees, an international treaty, and contracts with the
37 Secretary of the Interior.

38

39 Lead (Pb): A gray-white metal that is listed as a criteria air pollutant. Health effects from
40 exposure to lead include brain and kidney damage and learning disabilities. Sources include
41 leaded gasoline and metal refineries.

42

43 Lead agency (or agencies): Federal agency (or agencies) either preparing or taking primary
44 responsibility for preparing the NEPA compliance documents.

45

1 Lees Ferry: Reference point marking division between the Upper and Lower Colorado River
2 basins. The point is located in the mainstream of the Colorado River near the mouth of the Paria
3 River in Arizona. The historic location of Colorado River ferry crossings (1873 to 1928) and the
4 current site of the U.S. Geological Survey stream gage above the Paria River confluence.

5
6 Limnology: Scientific study of the physical, chemical, meteorological, and biological aspects of
7 freshwater bodies.

8
9 Listed species: Species, subspecies, or distinct population segments that have been added to the
10 federal list of endangered and threatened wildlife and plants and receive legal protection under
11 the ESA.

12
13 Load: Amount of electrical power or energy delivered or required at a given point.

14
15 Load-following: A pattern of hydropower generation that reacts instantaneously to change in
16 demand for power.

17
18 Loam: Soil consisting of an easily crumbled mixture of clay, silt, and sand.

19
20 Low flow: Flow releases from the dam at a rate of 8,000 cfs or less.

21
22 Lower Basin: Those parts of the states of Arizona, California, Nevada, New Mexico, and Utah,
23 within and from which waters drain naturally into the Colorado River below the Lees Ferry,
24 Arizona; defined by the Colorado River Compact of 1922.

25
26 Lower Colorado River Multi-Species Conservation Plan (MSCP): 50-year multi-stakeholder
27 federal and non-federal partnership set up to protect the lower Colorado River environment while
28 ensuring the certainty of existing river water rights and power operations; address the needs of
29 threatened and endangered native species and their habitats in compliance with state and federal
30 endangered species laws; and reduce the likelihood of listing additional species along the lower
31 Colorado River.

32
33 Lower Division: Division of the Colorado River system that includes the states of Arizona,
34 Nevada, and California; area defined by Article II of the Colorado River Compact of 1922.

35
36 Lower-elevation balancing tier: Operation elevation that applies when Lake Powell's projected
37 January 1 elevation is below 3,525 ft (1,074 m) above mean sea level (AMSL). The tier provides
38 for attempting to balance the contents of Lake Mead and Lake Powell, if possible, within the
39 constraint that the release from Lake Powell would not be more than 9.5 maf and no less than
40 7.0 maf.

41
42 **M**

43
44 Macroinvertebrate: Animal without vertebrae, usually with a hard exoskeleton or shell, of a size
45 large enough to be seen by the unaided eye.

46

- 1 Macrophyte (aquatic): Aquatic plant that is large enough to be observed with the naked eye.
2 Grows in or near water.
3
- 4 Main channel: Deepest or central part of the bed of a stream or river, containing the main
5 current.
6
- 7 Mainstem: Main course of a stream or river.
8
- 9 Mainstream: Principal or largest stream or river of a given area or drainage basin; in this
10 document, the Colorado River.
11
- 12 Major federal action: Proposed federal undertaking entirely or partly financed, assisted,
13 conducted, regulated, or approved by federal agencies that has the potential for significant
14 impacts on the human environment and is thus subject to federal control and responsibility.
15
- 16 Mammal: Air-breathing animal whose skin is more or less covered with hair or fur and has
17 mammary glands. Young are born alive (except for the platypus and echidna) and are nourished
18 with milk. Mammals include humans, dogs, cats, deer, mice, squirrels, raccoons, bats, opossums,
19 whales, seals, and others.
20
- 21 Management action: Decision-making response carried out to achieve a specific purpose.
22
- 23 Meander: Bends and loops in a river channel as the river snakes through a flat land area.
24
- 25 Mechanical removal (fish): Use of electrofishing, nets, and other gear types to physically remove
26 fish from an ecosystem. See electrofishing.
27
- 28 Median: Middle value in a distribution, above and below which lie an equal number of values.
29
- 30 Megawatt (MW): One million watts of electrical power.
31
- 32 Megawatt-hour (MWh): One million watt-hours of electrical energy.
33
- 34 Memorandum of Understanding (MOU): Document structuring the collaboration among federal
35 agencies and other stakeholders (e.g., Tribes, local governments) and describing an intended
36 common line of action.
37
- 38 Mesa: A broad, flat-topped elevation with one or more steeply sloping to vertical sides.
39
- 40 Mesozoic age: An era of geologic time between the Paleozoic and the Cenozoic eras, spanning
41 the time between 251 and 65 million years ago. The word Mesozoic is from Greek and means
42 “middle life.”
43
- 44 Metalimnion: Middle layer of a thermally stratified lake or reservoir where there exists a rapid
45 decrease in temperature with depth. Also called thermocline.
46

- 1 Meteorology: Study of the Earth’s atmosphere, particularly its patterns of climate and weather.
2
- 3 Metric ton: Unit of mass equal to 1,000 kilograms.
4
- 5 Microclimate: The climate of a small area, particularly that of the living space of a certain
6 species, group, or community.
7
- 8 Mid-elevation tier: Operation elevation that applies when Lake Powell’s projected January 1
9 elevation is below 3,575 ft (1,090 m) AMSL and at or above 3,525 ft (1,074 m) AMSL. The
10 annual releases in this tier are either 7.48 maf or 8.23 maf, depending upon the projected
11 elevation of Lake Mead being above or below 1,025 ft (312 m) AMSL, respectively.
12
- 13 Midge: A very small, non-biting, two-winged insect, related to deer flies, mosquitos, and
14 craneflies.
15
- 16 Mill: Monetary cost and billing unit used by utilities; equal to 1/1,000 of a U.S. dollar
17 (equivalent to 1/10 of one cent).
18
- 19 Milligram per liter: Equivalent to one part per million.
20
- 21 Million acre-feet (maf): Unit of volume; the volume of water that would cover one million acres
22 to a depth of one foot.
23
- 24 Mineral: Naturally occurring inorganic element or compound having an orderly internal structure
25 and characteristic chemical composition, crystal morphology, and physical properties such as
26 density and hardness. Minerals are the fundamental units from which most rocks are made.
27
- 28 Mitigation: Action implemented to eliminate, avoid, minimize, or reduce the severity of an
29 adverse impact on a particular resource resulting from the proposed action or its alternatives.
30 Mitigation can include one or more of the following: (1) avoiding impacts; (2) minimizing
31 impacts by limiting the degree or magnitude of an action; (3) rectifying impacts by restoration,
32 rehabilitation, or repair of the affected environment; (4) reducing or eliminating impacts over
33 time; and (5) compensating for the impact by replacing or providing substitute resources or
34 environments to offset the loss.
35
- 36 Modified low fluctuating flow (MLFF): Current operating flow regime for the Glen Canyon
37 Dam. The MLFF regime was established as the preferred alternative in the 1995 EIS and
38 subsequent 1996 Record of Decision (ROD). In general, MLFF combines reduced daily flow
39 fluctuations below the historic pattern of releases with high steady releases of short duration,
40 intended to protect or enhance downstream resources while allowing limited flexibility for power
41 operations. Established flows included minimum flows of no less than 8,000 cfs between 7 a.m.
42 and 7 p.m. and 5,000 cfs at night; maximum rate of release limited to 25,000 cfs during
43 fluctuating hourly releases; and releases of greater than 25,000 cfs (other than for emergencies)
44 made steady on a daily basis in response to high inflow and storage conditions.
45

- 1 Monoculture: the cultivation or growth of a single crop or organism, especially on agricultural or
2 forest land.
3
- 4 Monsoon: Rain event caused by a change in atmospheric circulation (e.g., wind direction) that
5 results in stormy conditions, including excessive rainfall.
6
- 7 Morphology: Form and structure of an object (e.g., biological organism or rock formation) or
8 any of its parts.
9
- 10 Mortality: Relative incidence or prevalence of death in a population.
11
- 12 Mouth (river): Natural opening, as the part of a stream or river, that empties into a larger body of
13 water (e.g., another river, lake, bay, or ocean).
14
- 15 Myxozoa: Group of small parasitic animals that live in aquatic environments; one species in this
16 group, *Myxobolus cerebralis*, is the parasite that causes whirling disease in rainbow trout.
17
- 18 N
19
- 20 National Ambient Air Quality Standards (NAAQS): Air quality standards established by the
21 CAA, as amended. The primary NAAQS specify maximum outdoor air concentrations of criteria
22 pollutants that would protect the public health within an adequate margin of safety. The
23 secondary NAAQS specify maximum concentrations that would protect the public welfare from
24 any known or anticipated adverse effects of a pollutant.
25
- 26 National Environmental Policy Act of 1969 (NEPA): Act passed by Congress in 1969 that sets
27 national policy, procedures, tools, and compliance measures to support environmental protection,
28 including encouraging productive harmony between people and their environment; promoting
29 efforts that will prevent or eliminate damage to the environment and the biosphere and simulate
30 the health and welfare of people; enriching the understanding of the ecological systems and
31 natural resources important to the nation; and establishing a Council on Environmental Quality.
32 It requires federal agencies to integrate environmental values into their decision-making
33 processes by considering the environmental impacts of their proposed actions and reasonable
34 alternatives to those actions. To meet this requirement, federal agencies prepare one of the
35 following: a categorical exclusion, an EA, or an EIS.
36
- 37 National Historic Preservation Act (NHPA): Federal law providing that property resources with
38 significant national historic value be placed on the *National Register of Historic Places*. It does
39 not require permits; rather, it mandates consultation with the proper agencies whenever it is
40 determined that a proposed action might affect a historic property.
41

- 1 *National Register of Historic Places* (NRHP): Official list of the nation’s cultural resources
2 worthy of preservation. Authorized under the National Historic Preservation Act of 1966, the
3 NRHP is part of a national program to coordinate and support public and private efforts to
4 identify, evaluate, and protect historic and archeological resources. Properties listed in the NRHP
5 include districts, sites, buildings, structures, and objects that are significant in American history,
6 architecture, archeology, engineering, and culture.
7
- 8 Native: Species of plants or wildlife that originated in the particular area or region in which they
9 are growing or living.
10
- 11 Native American: See American Indian.
12
- 13 Native American Graves Protection and Repatriation Act (NAGPRA): Act that established the
14 priority for ownership or control of Native American cultural items excavated or discovered on
15 federal or tribal land after 1990 and the procedures for repatriation of items in federal possession.
16 The act allows for the intentional removal or excavation of Native American cultural items from
17 federal or tribal lands only with a permit or upon consultation with the appropriate Tribe.
18
- 19 Natural condition: State or status of resources that would occur (to the extent practicable) in the
20 absence of human activities and/or dominance over the landscape.
21
- 22 Natural flow: The flow of any stream or river as it would be if unaltered by upstream diversion,
23 storage, import, export, or change in upstream consumptive use caused by human activities.
24
- 25 Natural resource: Features and values that are inherently supplied by nature and considered to
26 have value, including plants and animals, water, air, soils, topographic features, geologic
27 features, and paleontological resources.
28
- 29 Natural Zone: An area managed for the conservation of natural resources and ecological
30 processes while providing for their use by the public, as established by the National Park
31 Service.
32
- 33 Nearshore: Area located between the boundary of the mainstem current and the shoreline. These
34 regions are typically characterized by low water velocities (compared to the mainstem) and
35 reduced turbulent mixing.
36
- 37 Nematode: An elongated, cylindrical worm parasitic in animals, insects, or plants, or free-living
38 in soil or water.
39
- 40 Neotropical migratory bird: Bird that breeds in North America (i.e., Canada and the
41 United States) during the spring and summer months and spends the winter months in Mexico,
42 Central America, South America, or the Caribbean islands.
43
- 44 New High Water Zone (NHWZ): The area located next to the river, corresponding to river flows
45 of 25,000 to 40,500 cfs, colonized with vegetation since the construction of Glen Canyon Dam;
46 typically composed of riparian species, both native and nonnative.

- 1 Nitrate (NO₃): Naturally occurring plant nutrient that is essential to all life. It commonly enters
2 water supply sources from decaying plants, manures, fertilizers, or other organic residues.
3
- 4 Nitrogen dioxide (NO₂): Toxic reddish brown gas that is a strong oxidizing agent, produced by
5 combustion (as of fossil fuels). It is the most abundant of the oxides of nitrogen in the
6 atmosphere and plays a major role in the formation of ozone. NO₂ is one of the six criteria air
7 pollutants specified under Title I of the CAA. See nitrogen oxides.
8
- 9 Nitrogen oxides (NO_x): Includes various nitrogen compounds, primarily nitrogen dioxide and
10 nitric oxide. They form when fossil fuels are burned at high temperatures and react with volatile
11 organic compounds to form ozone, the main component of urban smog. They are also precursor
12 pollutants that contribute to the formation of acid rain.
13
- 14 No action alternative: An alternative required by CEQ to be included in all EAs and EISs,
15 representing conditions that would occur if the agency did not take the proposed action being
16 considered. The environmental effects resulting from taking no action are compared to the
17 effects of permitting the proposed action or any other action alternative to go forward.
18
- 19 Nonattainment area: The EPA's designation for an air quality control region (or portion thereof)
20 in which ambient air concentrations of one or more criteria pollutants exceed NAAQS.
21
- 22 Non-firm power: Power that is not available continuously and may be interruptible; may be
23 marketed on a short-term basis.
24
- 25 Nonnative: Species of plants or wildlife that did not originate in the particular area in which they
26 are growing or living and that often interfere with natural biological systems.
27
- 28 Non-use valuation: The process of assigning a non-use value to a resource.
29
- 30 Non-use value: The economic benefit that arises from the knowledge that a resource exists
31 (existence value), has been preserved for potential use in the future (option value), and will be
32 available for use by one's heirs (bequest value). Non-use value is theoretically and conceptually
33 distinct from use value. Contingent valuation is the only technique currently available for
34 estimating non-use value.
35
- 36 Normal condition: As it relates to the Colorado River, when the Secretary of Interior has
37 determined that there is available water for annual releases totaling 7.5 maf to satisfy
38 consumptive use in the Lower Division states pursuant to Article II(B)(1) of the Consolidated
39 Decree.
40
- 41 Notice of Intent (NOI): Announcement published in the *Federal Register* that an EIS will be
42 prepared and considered. Includes description of the proposed action and alternatives; provides
43 time, place, and descriptive details of the proposed scoping process; and identifies the lead
44 agency (or agencies) contact person.
45

- 1 NPS-28, Cultural Resource Management Guidelines: National Park Service guidelines that
2 elaborate on policies and standards and offers guidance in applying them to establish, maintain,
3 and refine park cultural resource programs.
4
- 5 Nutrients: Chemical elements or compounds that are essential to plant and animal growth and
6 development, such as nitrogen and phosphorus. Nutrients are measured in mg/L.
7
- 8 **O**
9
- 10 Obligate species: Restricted to a particular condition of life; for example, dependent on a
11 particular habitat to be able to breed.
12
- 13 Off-peak energy: Electric energy supplied during periods of relatively low system demand.
14
- 15 Old High Water Zone (OHWZ): Area of vegetation above the level corresponding to flood flows
16 of about 120,000 to 125,000 cfs; typically composed of native tree species.
17
- 18 On-peak energy: Electric energy supplied during periods of relatively high system demand.
19
- 20 Operating tier: Pursuant to the Interim Guidelines established in 2007 (DOI 2007), coordinated
21 operations of Lake Powell and Lake Mead defined four operation tiers: (1) Equalization Tier,
22 (2) Upper Level Balancing Tier, (3) Mid-Elevation Tier, and (4) Lower Elevation Balancing
23 Tier. See specific tiers for additional information.
24
- 25 Organic matter: Material derived from living plant or animal organisms.
26
- 27 Organochlorine pesticide: Pesticide containing a compound of carbon, chlorine, and hydrogen
28 that does not break down easily and is stored in fatty tissues of any animal ingesting it.
29 Accumulates in animals in higher trophic levels.
30
- 31 Oscillatoria: Genus of benthic (bottom-dwelling) cyanobacteria or plankton (blue-green algae)
32 occurring in blooms in fresh water.
33
- 34 Ostracod: Group of small crustaceans with a bivalved carapace that can be closed to completely
35 cover the body; important planktonic fish food.
36
- 37 Outage (power): Period during which a generating unit, transmission line, or other facility is out
38 of service and power is not available.
39
- 40 Outflow (hydrology): Amount or rate of water flowing out of or from a body of water. In this
41 report it refers to water leaving Lake Powell by way of Glen Canyon Dam.
42
- 43 Outlet works: Device, usually consisting of one or more bypass pipes or tunnels through the
44 embankment of the dam, used to release and regulate water flow from a dam. These structures
45 are similar in purpose to spillways, but outlet works can provide a lower volume and more
46 controlled release. See jet tube.

1 Ozone (O₃): Strong-smelling, reactive, toxic gas consisting of three oxygen atoms chemically
2 attached to each other. Ozone is formed in the atmosphere by chemical reactions involving NO_x
3 and volatile organic compounds (VOCs) in the presence of sunlight. Ozone is one of the six
4 criteria air pollutants under the CAA and is a major constituent of smog.

5
6 **P**

7
8 Paleoclimate: a climate prevalent at a particular time in the geologic past.

9
10 Paleoindian period: A late Pleistocene stage of cultural evolution in the Americas at the end of
11 the last ice age, when the first traces of human activity begin to appear in the archaeological
12 record characterized by big-game hunting and the use of fluted projectile points.

13
14 Paleozoic: An era of geologic time, from the end of the Precambrian to the beginning of the
15 Mesozoic, or from about 542 to 251 million years ago; also, the rocks deposited during this time.

16
17 Parasite: Organism that lives on or in an organism of another species (i.e., host) in a way that
18 harms or is of no advantage to the host. Parasites rarely kill their hosts, instead, they obtain
19 nutriment from the host body to live, grow, and multiply.

20
21 Particulate matter (pm): Fine solid or liquid particles such as dust, smoke, mist, fumes, or smog,
22 found in air or emissions that stick to lung tissue when inhaled. The size of the particulates is
23 measured in micrometers (µm), which is 1 millionth of a meter (0.000039 in.). Particle size is
24 important because the EPA has set standards for PM_{2.5} and PM₁₀ particulates, both of which are
25 criteria air pollutants under the CAA. See PM_{2.5} and PM₁₀.

26
27 Pathogen: Bacterium, virus, or other microorganism that can cause disease in other living
28 microorganisms or in humans, animals, and plants.

29
30 Peak demand: See peak load.

31
32 Peak flow: Maximum instantaneous flow in a specified period of time.

33
34 Peak load: Maximum electrical demand in a stated period of time.

35
36 Peak load plant: Powerplant that normally is operated to provide power during maximum load
37 periods.

38
39 Peaking power: Powerplant capacity typically used to meet the highest levels of demand in a
40 utility's load or demand profile.

41
42 Penstock: Conduit pipe used to convey water under pressure from a storage reservoir to the
43 turbines of a hydroelectric powerplant.

44
45 Per capita income: The average income per person in a given group.

46

- 1 Perennial stream: Stream that flows continuously throughout the year because it lies at or below
2 the groundwater table, which constantly replenishes it.
3
- 4 Periphyton: Complex mixture of algae, cyanobacteria, other microbes, and detritus that is
5 attached to submerged surfaces in most aquatic ecosystems. It serves as an important food source
6 for invertebrates, tadpoles, and some fish.
7
- 8 pH: A measure of the relative acidity or alkalinity of a solution, expressed in a scale of 0 to 14,
9 with a neutral point at 7. Acid solutions have pH values lower than 7, and basic (i.e., alkaline)
10 solutions have pH values higher than 7.
11
- 12 Phantom Ranch: Constructed in 1922, the Phantom Ranch is the only accommodations for hikers
13 in the inner Grand Canyon. It consists of a cluster of guest houses and a canteen lying between
14 Bright Angel Creek and the Colorado River in Grand Canyon National Park.
15
- 16 Phosphorous: Essential chemical food element that can contribute to the eutrophication of lakes
17 and other water bodies. Increased phosphorus levels result from discharge of phosphorus-
18 containing materials into surface waters.
19
- 20 Photosynthesis: Process in which chlorophyll-containing cells convert light into chemical
21 energy, forming organic compounds from inorganic compounds.
22
- 23 Phreatophyte: Any plant, typically living in the desert, that obtains its water from long taproots
24 that reach the water table.
25
- 26 Physiography: The physical geography of an area or the description of its physical features.
27
- 28 Phytoplankton: Microscopic, single-celled photosynthetic organisms that live suspended in
29 water.
30
- 31 Piscivorous: Habitually feeding on fish.
32
- 33 Plankton: Tiny plant (phytoplankton) and animal (zooplankton) organisms with limited powers
34 of locomotion usually living free in the water away from substrates.
35
- 36 Plano technological complex: Distinctive early Paleoindian culture defined by a range of
37 unfluted stone projectile points. Plano technology dates to 11,000 to 8,000 years ago.
38
- 39 PM₁₀: Particulate matter with a mean aerodynamic diameter of 10 µm (0.0004 in.) or less.
40 Particles with diameters smaller than this can be inhaled and accumulate in the respiratory
41 system. PM₁₀ is one of the six criteria pollutants specified under Title I of the CAA.
42
- 43 PM_{2.5}: Particulate matter with a mean aerodynamic diameter of 2.5 µm (0.0001 in.) or less.
44 Particles with diameters smaller than this can lodge deeply in the lungs. PM_{2.5} is one of the
45 six criteria pollutants specified under Title I of the CAA.
46

1 Pollinator: Agent, such as an insect or bird, that moves pollen from the male anthers of a flower
2 to the female stigma of a flower to accomplish fertilization.

3

4 Pollutant: Any material entering the environment that has undesired effects.

5

6 Ponding flow: Relatively high flows that produce warm low-velocity slackwater areas at
7 tributary mouths that provide thermal refuges for drifting larvae and young warmwater fish
8 (e.g., humpback chub).

9

10 Pool: Deep area of a stream or river between rapids or where the current is slow.

11

12 Post-dam: Period of time after the completion of Glen Canyon Dam in 1963.

13

14 Power demand: Rate at which electric energy is required and delivered to or by a system over
15 any designated period of time.

16

17 Power marketing: Process by which Western Area Power Administration sells power generated
18 at Glen Canyon Dam and other CRSP facilities that is subject to a number of requirements
19 established under statutory criteria.

20

21 Power operations: Physical operations of a large electrical power system, including hydropower
22 generation, control (operational flexibility, scheduling, load following, and reserves), and
23 transmission.

24

25 Power pool: Two or more interconnected electric systems that operate on a coordinated basis to
26 achieve economy and reliability in supplying their combined loads.

27

28 Powerplant: Structure that houses turbines, generators, and associated control equipment related
29 to the generation of electrical power.

30

31 Powerplant capacity: For Glen Canyon Dam, maximum flow that can pass through the turbines
32 when Lake Powell is full (33,200 cfs). Also refers to the electrical capacity of the generators;
33 total nameplate generating capacity for the powerplant is 1,021,248 kilowatts

34

35 Pre-dam: Period of time before the completion of the Glen Canyon Dam in 1963.

36

37 Predation: Act of preying or plundering, specifically the interaction between species when one
38 animal (predator) captures and eats another animal (prey).

39

40 Predatory: Relating to or characteristic of organisms that survive by preying on other organisms
41 for food.

42

43 Preference customer: In accordance with congressional directives, publicly owned systems, and
44 nonprofit cooperatives that have preference over investor-owned systems for purchase of power
45 from Federal projects.

46

- 1 Preferred alternative: Alternative the lead agency (or agencies) believes would fulfill its statutory
2 mission and responsibilities under NEPA, giving consideration to economic, environmental,
3 technical, and other factors.
4
- 5 Prescribed fires: Application of fire (by planned or unplanned ignitions) to fuels in either their
6 natural or modified states, under specified conditions, to allow the fire to burn in a predetermined
7 area while producing the fire behavior required to achieve certain management objectives.
8
- 9 Prevention of significant deterioration (PSD): A federal air pollution permitting program
10 intended to ensure that air quality does not diminish in attainment areas that meet NAAQS.
11
- 12 Primitive: Belonging to or characteristic of an early age of development.
13
- 14 Productivity (ecology): Rate of biomass generation by an individual, population, or community
15 within an ecosystem. Also, the fertility or capacity of a given habitat or area.
16
- 17 Programmatic Agreement (PA): Document that records the terms and conditions agreed upon to
18 resolve the potential adverse effects of a federal agency program, complex undertaking, or other
19 situations in accordance with Section 800.14(b), “Programmatic Agreements,” of 36 CFR
20 Part 800, “Protection of Historic Properties.”
21
- 22 Project area: Area in which a proposed action would occur and directly affect the environment.
23 The project area for the LTEMP EIS is Lake Powell, Lake Mead, and the Colorado River and its
24 corridor in between.
25
- 26 Proliferation: Rapid growth or increase in production of new parts or offspring.
27
- 28 Proposed action: An action proposed by an agency, subject to a NEPA analysis.
29
- 30 Proterozoic era: Final era of the Precambrian, spanning the time between 2.5 billion and
31 544 million years ago. Fossils of both primitive single-celled and more advanced multicellular
32 organisms begin to appear in abundance in rocks from this era. Its name means “early life.”
33
- 34 Protohistoric: Period between prehistory and history, during which a culture or civilization has
35 not yet developed writing but other cultures have already noted its existence in their own
36 writings. The protohistoric culture may also be in the process of developing its own writing
37 techniques and creating its own written record.
38
- 39 Public involvement: Process of obtaining public input into each stage of development of
40 planning documents. Required as a major input into any EIS.
41
- 42 **R**
43
- 44 Radionuclide: Unstable nuclide that undergoes radioactive decay.
45

- 1 Ramp rate: Rate of change (cfs/hr) in instantaneous dam releases. The ramp rate is established to
2 prevent undesirable effects due to rapid changes in loading or, in the case of hydroelectric
3 powerplants, discharge.
4
- 5 Range: Geographic region in which a given plant or animal normally lives or grows.
6
- 7 Rapid: Turbulent section of a river. Fast-flowing current typically is caused by a relatively steep
8 descent in the riverbed or a constriction of the main channel.
9
- 10 Reach: Any specified length of a stream or river.
11
- 12 Rearing: Bringing up from the early stages of life, through maturity, and until fully grown.
13
- 14 Reattachment bar: Sandbar located where downstream flow meets the riverbank at the
15 downstream end of a recirculation zone. An element of a fan-eddy complex.
16
- 17 Recirculation zone: Area of flow composed of one or more eddies immediately downstream
18 from a constriction in the channel, such as a debris fan or rock outcrop. An element of a fan-eddy
19 complex.
20
- 21 Reclamation Project Act of 1939: This act provides a comprehensive plan for the variable
22 payment of construction charges on U.S. reclamation projects.
23
- 24 Record of Decision (ROD): Document separate from but associated with an EIS that publicly
25 and officially discloses the responsible agency's decision on the EIS alternative to be
26 implemented.
27
- 28 Recovery: Return to or regain of any former and better state or condition. As it relates to ESA,
29 recovery is the process by which the decline of an endangered or threatened species is arrested or
30 reversed, and threats to its survival (including the ecosystem upon which they depend) are
31 neutralized, so that its long-term survival in nature can be ensured.
32
- 33 Recruitment: Survival of young plants and animals from birth to reproductive age or a life stage
34 less vulnerable to environmental change.
35
- 36 Redd: Depression, or spawning nest, dug by fish (especially trout or salmon) in river- or lakebed
37 for the deposition of eggs.
38
- 39 Redeposition: Formation into a new accumulation, such as the settlement of sedimentary
40 material that has been picked up and moved (reworked) from the place of its original deposition.
41
- 42 Refuge: Protection or shelter, as from something dangerous, threatening, harmful, or unpleasant.
43
- 44 Refugia: Locations or areas where conditions remain suitable to allow a species or a community
45 of species to survive following extinction in surrounding areas. Plural of refugium.
46

- 1 Region of influence (ROI): Area occupied by affected resources and the distances at which
2 impacts associated with a proposed action may occur.
3
- 4 Regulation: Capacity devoted to providing the minute-by-minute change in generation above and
5 below a generator's operating set point. It is needed to maintain a constant voltage within a
6 power control area given variation in generator units. Regulation results in instantaneous
7 deviations above and below the mean hourly flow within each hour that do not affect the mean
8 hourly flow over a full hour. In the United States, regulating capacity is controlled by computers
9 (via automatic generation control).
10
- 11 Reptile: Cold-blooded vertebrate of the class Reptilia whose skin is usually covered in scales or
12 scutes. Reptiles include snakes, lizards, turtles, crocodiles, and alligators.
13
- 14 Reserve generating capacity: Extra generating capacity available to meet unanticipated capacity
15 demand for power in the event of generation loss due to scheduled or unscheduled outages of
16 regularly used generating capacity.
17
- 18 Reservoir: Natural or artificially impounded body of water, commonly created by the building of
19 a dam, that is used for the storage, regulation, and control of water.
20
- 21 Reservoir capacity: Total or gross storage capacity of the reservoir at full supply level.
22
- 23 Restoration: Manipulation of the physical, chemical, or biological characteristics of a resource or
24 site with the goal of improving or returning its natural/historic functions to any former and better
25 state or condition.
26
- 27 Return-current channel: Channel excavated by upstream eddy flow that forms behind a
28 reattachment bar. See backwater.
29
- 30 Riffle: Stretch of choppy water caused by an underlying rock shoal or sandbar.
31
- 32 Riparian: Along a river, pond, lake, or tidewater.
33
- 34 Riparian zone: Area encompassing the alluvial sediment deposits where river and alluvial ground
35 water supplement that available from local precipitation.
36
- 37 Risk: Likelihood of suffering a detrimental effect as a result of exposure to a hazard.
38
- 39 River basin: Land area surrounding one river from its headwaters to its mouth. The area drained
40 by a river and its tributaries.
41
- 42 River corridor: River and the area of land adjacent to it, including the talus slopes at the bases of
43 cliffs, but not the cliffs themselves.
44

1 River mile (RM): Unit of measurement (in miles) that quantifies distance (or length) in miles
2 along a river from its mouth or other reference point. On the Colorado River, River Mile 0 is
3 located at the U.S. Geological Survey gage at Lees Ferry, Arizona; points downstream are
4 positive values while those upstream are negative.
5

6 River runner: Individual who recreationally navigates a moving body of water, typically a
7 whitewater river, using a raft, kayak, or other type of boat. See whitewater rafting.
8

9 River stage: Water surface elevation of a river above a reference datum.
10

11 Riverine: Of, resembling, relating to, or situated on a river or riverbank.
12

13 RiverWare: Commercial river system simulation computer program that was configured to
14 simulate operation of the Colorado River for this EIS.
15

16 Rotifer: Microscopic, multicellular invertebrates from the class Rotifera; common in freshwater.
17

18 Runoff: Portion of the precipitation, melted snow, or irrigation water that flows across ground
19 surface and eventually is returned to surface water sources. Runoff can pick up pollutants from
20 the air or land and carry them to the receiving waters.
21

22 S

23
24 Sacred landscape: Natural places recognized by a cultural group as having spiritual or religious
25 significance.
26

27 Sacred site: Any specific, discrete, narrowly delineated location on federal land that is identified
28 by an Indian Tribe, or Indian individual determined to be an appropriately authoritative
29 representative of an Indian religion, as sacred by virtue of its established religious significance
30 to, or ceremonial use by, an Indian religion; provided that the Tribe or appropriate authoritative
31 representative of an Indian religion has informed the agency of the existence of such a site.
32

33 Salinity: Degree of dissolved minerals (e.g., salts) in water. Also commonly referred to as total
34 dissolved solids (TDS). See total dissolved solids.
35

36 Salmonid: Of, belonging to, or characteristic of fish belonging to the Salmonidae family, which
37 includes salmon, trout, and whitefish.
38

39 Salt Lake City Area Integrated Projects (SLCA/IP): Part of an interconnected generation and
40 transmission system that includes federal, public, and private power-generating facilities.
41

42 Sand: Rock or mineral fragment of any composition that has a diameter ranging from 0.5 to
43 2.0 mm. Sand has a gritty feel.
44

- 1 Sand budget: Management tool used to analyze and describe the various sand and sediment
2 inputs (sources) and outputs (sinks) within a defined system; can be used to predict
3 morphological change over time.
4
- 5 Sand load: See sediment load.
6
- 7 Sand mass balance: Difference between the mass of sand being transported into an area and the
8 mass of sand being transported out of the area. A positive sand mass balance indicates that sand
9 is accumulating in the area, whereas a negative sand mass balance indicates that the mass of sand
10 is decreasing in the area.
11
- 12 Sandbar: Any of the fine-grained alluvial deposits that intermittently form the riverbank. These
13 fine-grained deposits are in contrast to the rocky surfaces predominately found throughout the
14 Grand Canyon. See beach.
15
- 16 Sandstone: Sedimentary rock composed primarily of sand-sized (0.0025 to 0.08 in.) grains.
17
- 18 Scheduled outage: Shutdown of a generating unit or other facility for inspection or maintenance,
19 in accordance with an advance schedule.
20
- 21 Scheduling: Matching of daily system energy and capacity needs with available generation.
22
- 23 Schist: Metamorphic rock formed from many types of rocks. Minerals in the rocks include
24 micas, chlorite, talc, hornblende, and garnets. The minerals are characteristically platy and
25 foliated (layered), indicating they were subjected to intense compression.
26
- 27 Scope: Range of actions, alternatives (including no action), and impacts to be considered in an
28 EIS.
29
- 30 Scoping: Process required by NEPA to solicit input, issues, and information from within the
31 agency, other agencies, and the public related to the proposed action prior to preparation of an
32 EIS. Scoping assists the preparers of an EIS in defining the proposed action, identifying
33 alternatives, and developing preliminary issues to be addressed in an EIS.
34
- 35 Scour: Erosion in or along a stream bed caused by high flow velocities.
36
- 37 Secretary: The Secretary of the Department of the Interior (DOI), and duly appointed successors,
38 representatives, and others with properly delegated authority.
39
- 40 Sediment: Unconsolidated solid material that is washed from land (e.g., from weathering of rock)
41 and is carried by, suspended in, or deposited by water or wind. Sediment varies in size and
42 includes clay, silt, sand, gravel, and cobble.
43
- 44 Sediment augmentation: Adding sand-, silt-, or clay-size sediments to the Colorado River to
45 increase turbidity or sediment supply.
46

- 1 Sediment load: Mass of sediment passing through a stream cross-section in a specified period of
2 time.
3
- 4 Sediment transport: Movement of sediment in a downstream direction caused by flowing water.
5
- 6 Sedimentary rock: Rock formed at or near the Earth's surface from the consolidation of loose
7 sediment that has accumulated in layers through deposition by water, wind, or ice, or organisms.
8 Examples are sandstone and limestone.
9
- 10 Sedimentation: Removal, transport, and deposition of sediment particles by wind or water.
11
- 12 Seep: Moist or wet place where groundwater slowly exits through soil or rock.
13
- 14 Seepage: Relatively slow movement of water through a medium, such as sand.
15
- 16 Semi-arid: Moderately dry region or climate where moisture is normally greater than under arid
17 conditions but still limits the production of vegetation.
18
- 19 Sensitive species: Plant or animal species listed by the state or federal government as threatened,
20 endangered, or a species of special concern. The list of sensitive species typically varies from
21 state to state, and the same species can be considered sensitive in one state but not in another.
22 Also, a species that is adversely affected by disturbance or altered environmental conditions.
23 See also special status species.
24
- 25 Separation bar: Sandbar located at the upstream end of a recirculation zone, where downstream
26 flow becomes separated from the riverbank, creating an eddy.
27
- 28 Shoal: Shallow area in a body of water.
29
- 30 Shortage condition: When the Secretary has determined that there is available for annual release
31 less than 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to
32 Article II(B)(3) of the Consolidated Decree.
33
- 34 Silt: Fine rock fragments or mineral particles of any composition between sand and clay in size
35 that have diameters ranging from 0.002 to 0.05 mm.
36
- 37 Simulid: Group of two-winged flying insects who live their larval stage underwater and emerge
38 to fly about as adults.
39
- 40 Sinuous: Ratio of the length of a river's thalweg to the length of the valley proper. A measure of
41 a river's meandering.
42
- 43 Site: In archeology, any location of past human activity.
44
- 45 Slope: Change in elevation per unit of horizontal distance.
46

- 1 Socioeconomic: Social and economic conditions in the study area.
2
- 3 Solar radiation: Electromagnetic radiation emitted by the sun.
4
- 5 Soundscapes: Sound or combination of sounds that forms or arises from an immersive
6 environment.
7
- 8 Spawn: To lay eggs, especially fish.
9
- 10 Spawning beds: Places where eggs of aquatic animals lodge or are placed during or after
11 fertilization.
12
- 13 Special status species: Any plant or animal species that is listed or proposed for listing as
14 threatened or endangered by the FWS or NMFS under the provisions of the ESA. Also any
15 species designated by the FWS as “candidate,” “sensitive,” or a “species of concern”; or a
16 species listed by a state in a category implying potential endangerment or extinction
17 (e.g., sensitive or rare).
18
- 19 Species of special concern: Species that may have a declining population, a limited occurrence,
20 or low numbers for any of a variety of reasons.
21
- 22 Spike flow: Natural or experimental increase in the flow of water for a short duration.
23
- 24 Spills: Water releases from Glen Canyon Dam that do not pass through the turbines for the
25 generation of electricity.
26
- 27 Spillway: Overflow channel of a dam to provide a controlled release.
28
- 29 Spinning reserves: Extra generating capacity that is available for immediate use in response to
30 system problems or sudden load changes by increasing the power output of generators that are
31 already connected to the power system. Within minutes or less, reserves allow for increases in
32 the water release rates at Glen Canyon Dam to increase power generation, up to a limit known as
33 the spinning reserve requirement, to compensate for the loss in generation elsewhere in the grid.
34
- 35 Spring: Point at which groundwater meets the Earth’s surface, causing water to flow from the
36 ground.
37
- 38 Stage: See water surface elevation.
39
- 40 Stakeholder: Person, group, or organization that has direct or indirect investment, share, or
41 interest in an organization or project because it can affect or be affected by related actions,
42 objectives, and/or policies.
43
- 44 State Historic Preservation Office(r) (SHPO): The state officer charged with the identification
45 and protection of prehistoric and historic resources in accordance with the National Historic
46 Preservation Act.

- 1 Steady flow: Flow released from the dam at any volume that does not vary beyond a small
2 percentage over a 24-hour period.
3
- 4 Stewardship: Conducting, supervising, managing, or protecting something considered of value or
5 worth caring for and preserving. The concept of stewardship has been applied in diverse areas,
6 including the environment, economics, health, property, information, and religion.
7
- 8 Strata: Single, distinct layers of sediment or sedimentary rock.
9
- 10 Stratification: Thermal layering of water in lakes and streams. Lakes usually have three zones of
11 varying temperature: epilimnion—top layer with essentially uniform warmer temperature;
12 metalimnion—middle layer of rapid temperature decrease with depth; and hypolimnion—bottom
13 layer with essentially uniform colder temperatures.
14
- 15 Stratigraphy: Layers of sediments and rocks that reflect the geologic history of an area. With
16 respect to cultural resources and archaeological sites, the relative stratigraphic locations of
17 human artifacts help determine the sequence in which past human activities took place.
18
- 19 Stream: Natural water course. See ephemeral stream, intermittent stream, and perennial stream.
20
- 21 Stream flow: Volume or rate, expressed in cubic feet per second (cfs), of water moving in a
22 stream or river, at any given time.
23
- 24 Stream gage: Active, continuously functioning field measuring device for which stream flow is
25 computed or estimated.
26
- 27 Subadult: Fish that are less than 3 years of age.
28
- 29 Subsistence: The practices by which a group or individual acquires food, such as through hunting
30 and gathering, fishing, and agriculture.
31
- 32 Substrate: Surface on which a plant or animal grows or is attached.
33
- 34 Sulfur dioxide (SO₂): Colorless gas released from many sources, especially burning fossil fuels.
35 Sulfur dioxide is one of the six criteria air pollutants specified under Title I of the CAA.
36
- 37 Sulfur oxides (SO_x): Compounds containing sulfur and oxygen, such as sulfur dioxide (SO₂) and
38 sulfur trioxide (SO₃). Pungent, colorless gases that are formed primarily by fossil fuel
39 combustion, notably from coal-fired powerplants. Sulfur oxides may damage the respiratory
40 tract, as well as plants and trees.
41
- 42 Surface water: Water on the Earth's surface that is directly exposed to the atmosphere, as
43 distinguished from water in the ground (groundwater).
44

1 Surplus condition: When the Secretary has determined that there is available for annual release
2 more than 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to
3 Article II(B)(2) of the Consolidated Decree.
4

5 Surplus energy: Energy greater than that of contracted firm load that may be available for a
6 short-term period to serve additional load; usually attributed to favorable, but unanticipated,
7 hydrologic conditions.
8

9 Suspended solids: Small particles of sand, silt, clay, and organic material moving with the water
10 or along the bed of the stream that are not in true solution (i.e., can be removed by filtration or
11 settling).
12

13 Suspension: Heterogeneous mixture of fine solid particles in a liquid or gas, such as sand in
14 water. The suspended particles will settle over time, if left undisturbed, or can be removable by
15 filtration.
16

17 Sustainable hydropower (SHP): Fixed level of long-term capacity and energy available from
18 SLCA/IP facilities during summer and winter seasons; this amount is the minimum commitment
19 level for capacity that Western will provide to all SLCA/IP customers.
20

21 Sweat lodge: In Native American culture, a ceremonial event of traditional prayers and songs
22 that are held in a lodge constructed of a wood frame covered with blankets, with hot stones that
23 release steam when water is poured on them.
24

25 T

26

27 Tailwater: Reach of river immediately downstream of a dam, where the water is more similar to
28 that in the reservoir than farther downstream.
29

30 Talus: Sloping accumulation of rock debris; also, rock fragments at the base of a cliff as the
31 result of sliding or falling.
32

33 Taxa: Taxonomic unit or category within the biological system of classification to which
34 organisms are assigned, including species, genus, family, order, class, and phylum.
35

36 Technical Work Group (TWG): Subcommittee comprised of technical representatives of the
37 Adaptive Management Work Group (AMWG) to develop criteria and standards for monitoring
38 and research programs.
39

40 Temperate: Moderate climate that lacks extremes in temperature.
41

42 Temperature control device (TCD): Apparatus used to modify the dam's penstocks to allow for
43 selective withdrawal from the reservoir, as to influence the temperature of the release water (e.g.,
44 warm surface water versus cold deep water).
45

46 Temporal: Of, relating to, or limited by time.

- 1 Temporary structure: Any structure that can be readily and completely dismantled and removed
2 from the site between periods of actual use. It may or may not be authorized at the same site
3 from season to season or from year to year.
4
- 5 Terrace: Surface form of a high sediment deposit having a relatively flat surface and steep slope
6 facing the river.
7
- 8 Terrain: Topographic layout and features of a tract of land or ground.
9
- 10 Terrestrial: Pertaining to plants or animals living on land rather than in water.
11
- 12 Texture: Visual manifestations of light and shadow created by the variations in the surface of an
13 object or landscape.
14
- 15 Thalweg: Line connecting the deepest points along the length of a valley or riverbed.
16
- 17 Thermal: Of, relating to, affected by, or producing heat.
18
- 19 Thermocline: Zone of maximum change in temperature in a water body, separating upper
20 (epilimnetic) from lower (hypolimnetic) zones.
21
- 22 Threatened species: Any species or subspecies that is likely to become an endangered species
23 within the foreseeable future throughout all or a significant portion of its range. Requirements for
24 declaring a species threatened are contained in the ESA of 1973.
25
- 26 Toe: Point at which the bottom of a slope or embankment intersects the natural ground, such as
27 the upstream or downstream toe of the dam or the downstream toe of a landslide or debris fan.
28
- 29 Topography: Physical shape of the ground surface; the relative position and elevations of natural
30 and human-made features of an area.
31
- 32 Total dissolved solids (TDS): Dissolved materials in the water including ions such as potassium,
33 sodium, chloride, carbonate, sulfate, calcium, and magnesium. In many instances, the term TDS
34 is used to reflect salinity, since these ions are typically in the form of salts. See salinity.
35
- 36 Toxicity: Harmful effects on an organism caused by exposure to a hazardous substance.
37 Environmental exposures are primarily through inhalation, ingestion, or the skin.
38
- 39 Trace (hydrology): Sequence of flows over a specified period of time.
40
- 41 Traditional Cultural Property (TCP): Site or resource that is eligible for inclusion in the NRHP
42 because of its association with cultural practices or beliefs of a living community that are
43 (1) rooted in that community's history, and (2) important in maintaining the continuing cultural
44 identity of the community.
45

- 1 Traditional use area: Broad landscapes over which contemporary people and their ancestors have
2 hunted, fished, and gathered.
3
- 4 Translocation: Intentional capture, movement, and release of individuals of a species from one
5 location or area to another. This type of transfer is typically done to prevent harm to the
6 individuals or to establish additional populations elsewhere.
7
- 8 Transmission line: Facility for transmitting electrical energy at high voltage from one point to
9 another point.
10
- 11 Travertine: Sedimentary rock formed by the precipitation of carbonate minerals from solution in
12 ground and surface waters, and/or geothermal hot springs.
13
- 14 Tribal land: In the NAGPRA, tribal land is defined as: (1) all lands within the exterior
15 boundaries of any Indian reservation; (2) all dependent Indian communities; and (3) any lands
16 administered for the benefit of Native Hawaiians pursuant to the Hawaiian Homes Commission
17 Act, 1920, and section 4 of Public Law 86-3. In the National Historic Preservation Act, tribal
18 land is defined as (1) all lands within the exterior boundaries of any Indian reservation, and
19 (2) all dependent Indian communities.
20
- 21 Tribe: Term used to designate a federally recognized group of American Indians and their
22 governing body. Tribes may be comprised of more than one band.
23
- 24 Tributary: River or stream that flows into another stream, river, or lake.
25
- 26 Trigger: Condition-dependent or environmental cues that determine management actions.
27
- 28 Trophic: Of, relating to, or pertaining to nutrition, food, or feeding. For example, the feeding
29 habits or food relationship of different organisms in a food chain.
30
- 31 Trout: Prized game fish native to the Northern Hemisphere, that has been widely introduced
32 (i.e., it is nonnative) across the globe, including the Colorado River below Glen Canyon Dam
33 (with exception of the native cutthroat trout). These fishes feature a streamlined, speckled body
34 with small scales and soft fins, although their individual coloring and appearance can change
35 depending on the specific surroundings and environment in which they live. Typically smaller
36 than the related salmon, trout are usually found in cool (50–60°F, 10–16°C), clear freshwater
37 streams and lakes. Trout are an important food source for humans and wildlife including brown
38 bears, birds of prey (e.g., eagles), and other animals. However, their existence threatens many
39 native fish species and their habitats owing to competition, displacement, and predation.
40

1 Trout management flow (TMF): Special type of fluctuating flow designed to reduce the
2 recruitment of trout by disadvantaging young-of-the-year (YOY) trout. Trout management flows
3 have been proposed and developed on the basis of research conducted by Korman. Trout
4 management flows feature repeated fluctuation cycles that consist of relatively high flows
5 (e.g., 20,000 cfs) sustained for a period of time (potentially ranging from 2 days to 1 week)
6 followed by a rapid drop to a low flow (e.g., 5,000 to 8,000 cfs). This low flow would be
7 maintained for a period of less than a day (e.g., 12 hr) to prevent adverse effects on the food
8 base. Low flows would be timed to start in the morning, after sunrise, to expose stranded fish to
9 direct sunlight and heat. In a trout management flow cycle, YOY trout are expected to occupy
10 nearshore habitat near the maximum flow elevation; they would be subsequently stranded by the
11 sudden drop to low flow. Trout management flows would be used to control trout recruitment in
12 the Glen Canyon reach, and ultimately to limit emigration of juvenile trout to downstream
13 reaches, particularly to habitat occupied by humpback chub near the confluence with the Little
14 Colorado River.

15
16 Turbidity: Measure of the water clarity or the ability of light to pass through water. Affected by
17 the amount of suspended particles, dissolved solids, and colloidal materials that are suspended in
18 water.

19
20 Turbine: Device or machine for generating rotary mechanical power from the energy of a stream
21 of fluid (such as water, steam, hot gas, or wind). Turbines convert the kinetic energy of fluids to
22 mechanical energy through the principles of impulse and reaction, or a mixture of the two.
23 Turbines are considered the most economical means of turning large electrical generators.

24
25 Turbulent: Marked or characterized by disturbances, changes, and unrest, such as unsteady
26 motion and agitation of water.

27
28 **U**
29
30 Upper Basin: Those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming,
31 within and from which waters drain naturally into the Colorado River above the Lees Ferry,
32 Arizona; defined by the Colorado River Compact of 1922.

33
34 Upper Colorado River Commission: Commission established by the Upper Colorado River Basin
35 Compact with five appointed members from the Upper Division States (Colorado, New Mexico,
36 Utah, Wyoming) whose purpose is to secure the storage of water for beneficial consumptive use
37 in the Upper Basin.

38
39 Upper Division: Division of the Colorado River system that includes the states of Colorado,
40 New Mexico, Utah, and Wyoming; area defined by Article II of the Colorado River Compact
41 of 1922.

42

- 1 Upper-elevation balancing tier: Operation elevation that applies when Lake Powell’s projected
2 January 1 elevation is below the elevation in the equalization table of the Interim Guidelines, but
3 above 3,575 ft (1,090 m) AMSL. The tier defines several different operations for attempting to
4 balance the contents of Lake Mead and Lake Powell, if possible, that may occur based on the
5 projected elevations of each lake, within the constraint that the release from Lake Powell would
6 not be more than 9.0 maf and no less than 7.0 maf.
7
- 8 Upstream: Toward the source of a stream or river, against the normal direction of water flow.
9
- 10 Use value: Economic benefit associated with the physical use of a resource, usually measured by
11 the consumer surplus or net economic value associated with such use. The contingent value
12 method is one technique used to estimate use value.
13
- 14 **V**
15
- 16 Varial zone: Portion of the river bottom that is alternately flooded and dewatered.
17
- 18 Velocity: Rate of flow of water or water-sediment mixture.
19
- 20 Vertebrate: Animal species with a backbone including fish, amphibians, reptiles, birds, and
21 mammals.
22
- 23 Visibility degradation: Scattering and absorption of light by fine particles with a secondary
24 contribution by gases; cumulative emissions of air pollutants from a myriad of sources.
25
- 26 Visitor day: Use of a site or area for 12 visitor hours, which may be aggregated by one or more
27 persons for a single continuous or intermittent use (e.g., multiple visits).
28
- 29 Visitor use: Usage of recreation and wilderness resources by people for inspiration, stimulation,
30 solitude, relaxation, education, pleasure, or satisfaction.
31
- 32 Visual contrast: Opposition or unlikeness of different forms, lines, colors, or textures in a
33 landscape.
34
- 35 Visual impact: Any modification in land forms, water bodies, or vegetation, or any introduction
36 of structures that negatively or positively affect the visual character or quality of a landscape
37 through the introduction of visual contrasts in the basic elements of form, line, color, and texture.
38
- 39 Visual resource: Refers to all objects (manmade and natural, moving and stationary) and features
40 such as landforms and water bodies that are visible on a landscape.
41
- 42 Volatile organic compound (VOC): Broad range of organic compounds that readily evaporate at
43 normal temperatures and pressures. Sources include certain solvents (e.g., acetone), degreasers
44 (e.g., benzene), and fuels (e.g., gasoline). VOCs also react with other substances (primarily
45 nitrogen oxides) to form ozone. They contribute significantly to photochemical smog production
46 and certain health problems.

1 **W**

2

3 Warmwater fish: Species of fish that grow best in water at least 80°F (27°). Warm water holds
4 less DO than cool or cold water, so warmwater species, such as largemouth bass, catfish, and
5 bluegill, require less oxygen to survive.

6

7 Wash: Normally dry streambed that occasionally conveys flowing water.

8

9 Water column: Hypothetical “cylinder” of water from the surface of a water body to the bottom
10 and within which physical and chemical properties can be measured.

11

12 Water quality: Term used to describe the chemical, physical, and biological characteristics of
13 water, usually with respect to its suitability for a particular purpose.

14

15 Water right: Legal entitlement of an individual or entity to extract water from a water source
16 (surface water or groundwater) for a beneficial use (e.g., potable water supply, irrigation, mining,
17 livestock).

18

19 Water table: Upper level of ground water below which soil and rock are saturated with water.

20

21 Water year: Period of time beginning October 1 of one year and ending September 30 of the
22 following year and designated by the calendar year in which it ends.

23

24 Waterfowl: Water birds, usually referring to ducks, geese, and swans.

25

26 Watershed: Region or area from which all water entering a particular water body drains. Also
27 known as a basin.

28

29 Water-surface elevation (stage): Height, or elevation, of a water surface above or below an
30 established reference level, such as sea level.

31

32 Weed: Plant considered undesirable, unattractive, or troublesome, usually introduced and
33 growing without intentional cultivation.

34

35 Western Area Power Administration (Western): One of four power marketing administrations of
36 the U.S. Department of Energy that markets and delivers reliable, renewable, cost-based
37 hydroelectric power and related services within a 15-state region of the central and western
38 United States.

39

40 Western Electricity Coordinating Council (WECC): Regional entity responsible for coordinating
41 and promoting bulk electric system reliability in the Western Interconnection.

42

43 Wetlands: Federally protected areas that are saturated or flooded by surface or groundwater
44 frequently enough or long enough to support plants, birds, and animals adapted to live in wet
45 environments. Generally include swamps, marshes, bogs, estuaries, wet meadows, river
46 overflows, mud flats, natural ponds, and other inland and coastal areas.

1 Wheeling: Occurs when two indirectly connected utilities agree to purchase or sell power to each
2 other.

3
4 Whirling disease: Disease caused by a parasite; results in neurological damage to young fish,
5 causing them to swim in a corkscrew pattern. Affected fish are unable to feed properly and are
6 vulnerable to predators.

7
8 Whirlpool: Water moving rapidly in a circle so as to produce a depression.

9
10 Whitewater boating: See whitewater rafting.

11
12 Whitewater rafting: Recreational navigation of a moving body of water (e.g., river) characterized
13 by fast-flowing rough water or rapids, using a raft, kayak, or other type of boat.

14
15 Wild and Scenic Rivers Act: Primary river conservation law enacted in 1968. The Act was
16 specifically intended by Congress to balance the existing policy of building dams on rivers for
17 water supply, power, and other benefits, with a new policy of protecting the free-flowing
18 character and outstanding values of other rivers.

19
20 Wilderness: Undeveloped land retaining its primeval character without permanent improvements
21 or human habitation, and that generally appears to have been affected primarily by the forces of
22 nature, with the imprint of man's work substantially unnoticeable.

23
24 Wilderness Act of 1964: Legislation enacted in 1964 to designate wilderness areas, with
25 Congressional approval, to ensure that these lands are preserved and protected in their natural
26 condition.

27
28 Wilderness areas: Areas and lands designated by Congress and defined by the Wilderness Act of
29 1964 as places "where the earth and its community are untrammelled by man, where man himself
30 is a visitor who does not remain." Designation is aimed at ensuring that these lands are preserved
31 and protected in their natural condition.

32
33 Wilderness characteristics: Wilderness characteristics include (1) naturalness: the area generally
34 appears to have been affected primarily by the forces of nature, with the imprint of man's work
35 substantially unnoticeable; (2) outstanding opportunities: the area has either outstanding
36 opportunities for solitude, or outstanding opportunities for primitive and unconfined types of
37 recreation; (3) size: the area is at least 5,000 acres (20 km²) of land, or is of sufficient size to
38 make practicable its preservation and use in an unimpaired condition; and (4) values: the area
39 may also contain ecological, geological, or other features of scientific, educational, scenic, or
40 historical value.

41
42 Willingness to pay: Method of estimating the value of activities, services, or other goods, where
43 value is defined as the maximum amount a consumer would be willing to pay for the opportunity
44 rather than do without. The total willingness to pay, minus the user's costs of participating in the
45 opportunity, defines the consumer surplus and benefits.

46

1 Wind rose: Circular diagram, for a given locality or area, showing the frequency and strength of
2 the wind from various directions over a specified period of record.

3

4 World Heritage Site: Area identified by the World Heritage Committee of the United Nations
5 Educational, Scientific, and Cultural Organization (UNESCO) as having outstanding universal
6 value for cultural and natural heritage.

7

8 **X**

9

10 Xeric: Low in moisture. Dry environmental conditions. Habitats or sites characterized by their
11 limited water availability.

12

13 **Y**

14

15 Young-of-year (YOY): Young (usually fish) produced in the current calendar year. Also referred
16 to as age 0.

17

18 **Z**

19

20 Zooplankton: Small, usually microscopic animals (such as protozoans), found in lakes and
21 reservoirs. Zooplankton can be permanent (i.e., rotifers or cladocerans) or temporary, as with the
22 early life stages (i.e., eggs, larvae, juveniles, and adults) of many fish and invertebrate species.